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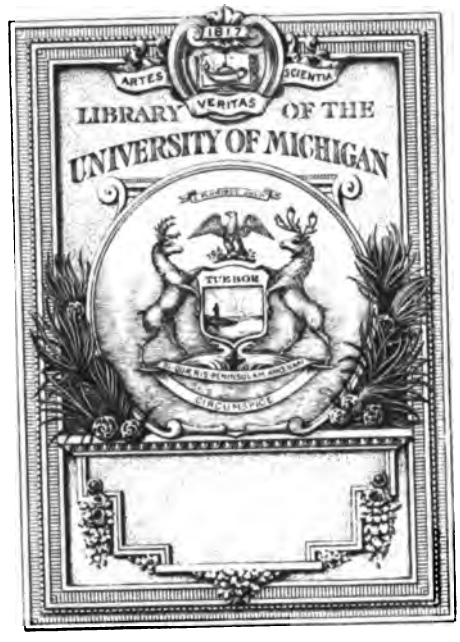

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OF THE

INSTITUTION OF NAVAL ARCHITECTS.

VOLUME X.

1869.

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CONTENTS.

PAGE.

List of Officers v

List of Honorary Members, Honorary Associates, Members, and Associates vii

Objects of the Institution xiii

Bye-Laws and Regulations xiii

Introduction xvii

PAPERS AND DISCUSSIONS.

On the Law of Resistance of Armour Plates, composed of One or More Thicknesses. By WILLIAM FAIRBAIRN, Esq., C.E., LL.D., F.R.S., Honorary Associate 1

Discussion on the above Paper 14

On the Iron Floating Dock of Carthagena, its Proportions and Relative Stability. By GEORGE B. RENNIE, Esq., M.I.C.E., Associate 17

On a Project for a Floating Dock. By CHARLES H. WIGRAM, Esq., Member of Council 23

Discussion on the two preceding Papers 26

On the Progress of Liquid Fuel. By Captain JASPER H. SELWYN, R.N. 32

Discussion on the above Paper 37

On Railway Communication across the Sea. By JOHN SCOTT RUSSELL, Esq., F.R.S., Vice-President . . 47

Discussion on the above Paper 55

On Long and Short Iron-clads. By E. J. REED, Esq., C.B., Chief Constructor of the Navy, Vice-President 59

Discussion on the above Paper 77

On the Hydraulic Steering Gear, as being fitted to H.M.S. *Achilles*. By Captain EDWARD AUGUSTUS INGLEFIELD (now Rear-Admiral Inglefield, C.B.), R.N., F.R.S. 92

Discussion on the above Paper 98

On the Steam Steering Apparatus, fitted in the *Great Eastern*, and H.M. Ships *Northumberland* and *Monarch*. By JOHN MAC FARLANE GRAY, Esq., Shipwright and Engineer Surveyor to the Honorable the Board of Trade 101

Discussion on the above Paper 112

On the Qualities of Boiler Plate. By S. M. SAXBY, Esq., R.N., Associate 119

Discussion on the above Paper 130

On the Calculation of the Stress in Propeller Shafts. By W. J. MACQUORN RANKINE, Esq., C.E., LL.D., F.R.S., Assoc. Mem. Council 139

Digitized by Google

PAGE.

On the Resistance opposed by Water to the Motion of Vessels of various Forms, and the way in which this varies with the Velocity. By JOHN I. THORNYCROFT, Esq., C.E. 144

Discussion on the above Paper 148

On the Preservation of Life at Sea by Life Buoys and Rafts. By Staff-Commander W. S. BOURCHIER, R.N. 155

Discussion on the above Paper 163

On Copper Sheathing for Iron Ships, considered at the Present Stage of our Experience. By JOHN GRANTHAM, Esq., Member of Council 166

On Zinc Sheathing for Ships. By BENJAMIN BELL, Esq. 174

Discussion on the two preceding Papers 182

On the Location of Independent Steam Fire and Bilge Pumps in Steamers. By CHARLES H. HASWELL, Esq., Civil and Marine Engineer, New York, U.S., Associate 197

On Horse-Power. By J. S. HOLLAND, Esq., C.E., R.N., Associate 201

On an Instrument for Determining the Deviation of Ships' Compasses. By W. F. REYNOLDS, Esq. . . . 203

On Sea-going Turret Ships. By Vice-Admiral E. PARIS, C.B., French Imperial Navy, Membre de l'Institut (Académie des Sciences), Associate. 206

Concluding Proceedings 219

Nominal Index 227

ERRATA.

VOLUME IX.—Page 15. In the Table and Diagrams, for "5, 6, 7, 8, 9, 10, 11," *read* 1, 2, 3, 4, 5, 6, 7.

PRESENT VOLUME.—Page 86, line 5 from bottom. For "fire-part," *read* fore-part.

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THE objects of the INSTITUTION OF NAVAL ARCHITECTS—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads:—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made, then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. THE INSTITUTION OF NAVAL ARCHITECTS shall consist of four classes, *viz.*, Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The Class of Members shall consist exclusively of Naval Architects and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified, either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

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7. A General Meeting of the Members and Associates of the Institution shall be held annually; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the Election of Associate Members of Council, the Treasurer and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly-elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all Meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present, to preside.

13. The Chairman at any Meeting of the Council or of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of Council shall form a *quorum*.

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding Meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide

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for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council, and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

30. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, *viz.:* M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

31. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulation:—

He shall submit to the Council a statement, showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

32. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, and such four-fifths constitute a majority of the professional Members of the Council, his proposal for admission shall be

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submitted to the Members of the Institution (who shall have access to the applicant's statement) at an Ordinary Meeting of the Institution, for them to vote upon, by ballot.

33. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon by ballot.

34. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

35. Each Member and Associate shall pay an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

36. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

MEETINGS.

37. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

38. The Transactions of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

39. The Transactions shall not be sold, or supplied for sale, by the Institution; but a copy shall be sent free to each Member and Associate.

40. Members and Associates are particularly requested to communicate to the Secretary any change of address.

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INTRODUCTORY PROCEEDINGS.

THE Annual Meetings of this, the Tenth Session of the Institution of Naval Architects, were held in the Hall of the Society of Arts, John Street, Adelphi, on Thursday, Friday, and Saturday, March 18th, 19th, and 20th, 1869.

The Opening Meeting took place on Thursday, at 12 o'clock, and was presided over by the Right Hon. Sir JOHN S. PAKINGTON, Bart., M.P., G.C.B., D.C.L., President of the Institution. The proceedings were commenced by the President calling upon the Honorary Secretary, Mr. CHARLES W. MERRIFIELD, to read the Report of the Council, which was as follows:—

REPORT OF THE COUNCIL, 18th MARCH, 1869.

"The Council have great pleasure in congratulating the Institution on the useful work which it has "done during the past and previous years.

"The Members and Associates are aware that the Institution received a Grant of £250 from Her "Majesty's Government in April, 1868: the Council are happy to state that this Grant has been renewed "by the present Government.

"If the Grant should be continued—as the Council hope—there will be no further difficulty about "the financial position of the Institution. The Council have not thought fit on this account to relax their "vigilant supervision over economy of expenditure, and are happy to state that important reductions "have been effected by changes, which, in their belief, will tend to promote efficiency.

"The Offices of the Institution have been removed to No. 9, Adelphi Terrace. The new premises "are more convenient than the former ones, and they are held at a considerable reduction of rental. "The expenses of removal will, however, absorb the saving in rent for the current year.

"The Council have always strongly felt that the affairs of the Institution could not be regarded as "permanently settled until (as provided by the Rules) a highly qualified Secretary could be engaged "at a proper salary. The state of the finances does not render this possible at present. The "Honorary Secretary still conducts the ordinary business of the office; but the Council, after due "consideration, and after ample notice, have dispensed with the services of the Assistant Secretary, and "have allowed the Honorary Secretary to engage one of the former Students of the present School of "Naval Architecture as clerk.

"They consider it due to Mr. Campbell to state that they were fully satisfied with his assiduity, "industry, and integrity. The main reason for dispensing with his services was, that practical "inconveniences arose from the person in charge of the Office being without any technical knowledge "of Naval Architecture.

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" The School of Naval Architecture and Marine Engineering at South Kensington is still watched " with great solicitude by the Council. The Science and Art Department, in concurrence with the " Admiralty, have recently extended the course of instruction from three to four years, and have " lengthened the School session from six months to seven months in each year. By this change it is " hoped that a sounder character will be communicated to the instruction—especially in the applied " subjects and technical education—than was possible when so extensive a programme had to be got " through in the short space of eighteen months of study. The School is beginning to have its value " generally recognised. Since the second year of its establishment it has never been without Foreign " students, and the Egyptian Government has recently sent over five young men to be taught Marine " Engineering and Naval Architecture in it.

" The Council beg leave to recommend to the consideration of the General Meeting, a Rule allowing " of the admission of Marine Engineers conversant with Naval Architecture to be full Members instead " of Associates of the Institution.

" In the event of your adopting this Resolution, the Council would suggest to you for consideration " whether it might not be expedient to confer upon the Council, as an extraordinary measure for the " present year, the power of admitting as Members of the Institution such distinguished Engineers as " the Council may think proper, without the usual forms of special credentials and the submission of " the names to a General Meeting."

[BALANCE SHEET

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Institution of Naval Architects.

Balance Sheet as at 31st December, 1868.

Dr.

1867.				£	s.	d.
Dec. 31.	To Balance :—					
	In Treasurer's hands	54	16 0			
	In Assistant Secretary's hands	24	15 7			
				79	11	7
1868.						
Dec. 31.	„ Cash received :—					
	Annual Subscriptions	750	9 6			
	Life Subscription	31	10 0			
	Volumes sold to Members and Associates	14	14 0			
	Admiralty Grant ..	250	0 0			
				1,046	13	6
				£1,126	5	1

Cr.

1868.				£	s.	d.
Dec. 31.	By Cash paid :—					
	Rent of Rooms, five quarters to 25 Dec., 1868	150	0 0			
	Cleaning ditto, four quarters, to 31 Dec., 1868	13	0 0			
				163	0	0
	Advertising, Session 1867	43	15 6			
	Attendance, ditto 1868	9	6 0			
	Reporting Discussions ditto	21	0 0			
	Paid *Engineering* for Abstract of Proceedings, Session, 1868	15	15 0			
				89	16	6
	Copper-Plate Engraving :					
	Vol. VII., Balance of account.....	82	4 0			
	Vol. VIII., to account	30	0 0			
	Printing Vol. VII., and sundry Printing, 1866-67	305	18 6			
	Charges for distribution of Vol. VIII.	16	5 9			
	Reducing Drawings for Vol. IX.	13	9 6			
				447	17	9
	Assistant Secretary's Salary, between 21st Dec., 1867, and 29th Dec., 1868	154	15 9			
	Clerk's Salary, three months, to 23rd Dec.	25	0 0			
	Messenger's and Occasional Clerk's Salaries	18	17 8			
				198	13	5
	Fire Insurance to March 25th, 1869			1	15	0
	Stationery for 1867			12	2	3
	Rent and Repairs of Furniture.....			17	13	2
	Postages			28	1	1
	Sundry Petty Disbursements			30	5	0
	By Balance :—					
	In Treasurer's hands ...	131	16 0			
	In Assistant Secretary's hands	5	4 11			
				137	0	11
				£1,126	5	1

E. & O. E.
March 15th, 1869.

J. LUKE,
NATH^L. BARNABY, } *Auditors.*
JOSEPH D'A. SAMUDA, *Treasurer.*
CHAS. CAMPBELL, *Assistant Secretary.*

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The List of Donations to the Library of the Institution was next read by the Secretary, and the thanks of the Meeting were ordered to be given to the Donors.

The List was as follows:—

"A Treatise on Iron Shipbuilding, with Practical Illustrations." By JOHN GRANTHAM, Member of Council, I.N.A. *Presented by the Author.*

"A Treatise on Shipbuilding, Theoretical and Practical." By Colonel OCOUNEFF, Naval Architect of the Russian Imperial Navy, M.I.N.A. *Presented by the Author.*

"Shipbuilding in Iron and Steel: a Practical Treatise." By E. J. REED, C.B., Chief Constructor of the Navy, Vice-President, I.N.A. *Presented by the Author.*

"Reports of the United States Patent Office for 1865 and 1866." *Presented by the Hon. the Commissioner of Patents, Washington.*

"Catalogue of the Melbourne Public Library." *Presented by the Trustees.*

"Projet de Navire de Mer à Tourelles." Par M. le Vice-Admiral PARIS. *Presented by the Author.*

The following List of Names of Gentlemen proposed as Members of the Institution, and recommended by the Council for election was then read, and put to the vote. They were elected, *nem. con.*:—

Colonel Michael Ocouneff, Naval Architect of the Russian Imperial Navy.
Senhor Trajano Augusto de Carvalho, Assistant Constructor of the Brazilian Imperial Navy.
Mr. Jamsetjee Dhunjabhoy Wadia, Master Builder, H.M. Dockyard, Bombay.

The List of Officers of the Institution was then read, together with the names of certain Gentlemen proposed to be added to the list. These proposed additions were the Right Hon. Hugh C. E. Childers, M.P., First Lord of the Admiralty; Lord John Hay, C.B., M.P., Captain R.N., a Lord of the Admiralty, as Vice-Presidents; Andrew Murray, Esq., Member I.N.A., as Member of Council; and Henry Green, jun., Esq., Associate I.N.A., as Associate Member of Council.

Mr. SCOTT RUSSELL moved that the existing Officers of the Institution be re-elected, and that the new names be added to the list as proposed. This Resolution was put to the vote and carried unanimously.

The President then delivered the following Inaugural Address:—

I now rise, in compliance with what has been the usual custom in this Institution, to open our proceedings by a few observations.

I am sorry to say that the preliminary business of the Council occupied our time rather longer than usual this morning, and prevented our appearance in this room with that punctuality which I think is always desirable in matters of public business. I hope, under the circumstances, the Meeting will excuse that deviation from punctuality, and it will be my duty not to detain you longer than I feel to be necessary with any preliminary observations.

But I cannot reconcile it to myself to commence these remarks without in the first place expressing the very great satisfaction it gives me to meet the Members of this important Institution at this Annual Session, and to repeat the regret which I was obliged to communicate to you last year for my inability, from accidental causes, to take my usual place in this chair on that occasion. The result, I am sorry to say, is that I have not had the honour of meeting you for two years; and during those two years I have found myself obliged to turn my attention from "blue jackets" to "red jackets,"

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and therefore I have been unable to devote my attention to naval affairs to that extent which both by taste and by habit, I am inclined to do (hear, hear), and I am less than ever competent to address you upon those subjects which have brought us here to-day.

But as time passes on, and as year after year we receive that interesting volume which contains the Transactions of each Annual Session, I confess I become, and I hope it is the case with others, more and more impressed with the fitness of this Institution to promote the great objects which it has in view. Of the importance of those objects it is impossible for any reflecting mind to doubt. And it is equally impossible to see assembled here a number of men who, by their long experience and scientific acquirements, are competent to communicate most valuable knowledge, and to communicate both in writing and speech the results of their investigations, without feeling that by such means the stock of knowledge which we possess upon subjects connected with Naval Architecture must be increased to the great benefit of professional men, and of the country whose interests they have at heart.

With this strong opinion of the great and increasing value of this Institution, I am pleased to be able to congratulate you upon the contents of the Report which has just been read. It will be my duty to-day to do that which, if I remember aright, has not always been done, but which, I think, ought always to be done on these occasions, namely, to conclude my observations by moving the adoption and approval of the Report, so that the changes recommended in the Report may thus receive the confirmation of the whole body of the Members of the Institution assembled here to-day. And, Gentlemen, I cannot allude to the contents of the Report, without stating my opinion—an opinion I am the more free to express because it has not been in my power to attend the Meetings of the Council for the last two years—that our thanks are due not only to the Council, but to our able and excellent Honorary Secretary, for the great care, attention, and success with which the affairs of this Institution have hitherto been managed (Hear, hear).

I turn with great satisfaction to another important part of our affairs. I allude to our financial position. Whether in the affairs of nations, or in the affairs of institutions of this kind, a prosperous financial condition is one of the first requirements for power and success. It must, therefore, be highly satisfactory to the Members of the Institution to have heard that paragraph of the Report which relates to our finances. I am also glad to be able to state to you that the hope held out at the last Annual Meeting, that during the then ensuing year our expenses would be within our income, has been fully realised—I believe realised for the first time. It must be very satisfactory also to the Institution to be informed that, following the example of the last Government—who gave a donation of £250 towards the expenditure of this Institution, regarding it, and confirming it, if I may say so, as an institution of great national importance—the present Government have adopted the same course. Looking to this fact, that we have not only received this assistance for two successive years, but have received it from two successive Ministries, I think we are justified in the expectation that, as long as the affairs of the Institution require it, we may look forward to receiving similar assistance year after year. The financial difficulty, which, you are aware, had existed for some little time, has thus been entirely terminated, and, although the Council are still of opinion that an economical and prudent management of our affairs is necessary, yet I think I shall not be too sanguine if I express the hope that the prosperous career of this Institution will not hereafter be impeded or endangered by financial difficulty (Hear, hear).

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There is another subject touched upon in this Report, which has always been regarded by this Institution with great and natural interest. I refer to the progress of the School of Naval Architecture. I hardly know whether I ought to speak of the School of Naval Architecture as a sister Institution, or whether we do not rather stand towards each other in the relation of mother and daughter. In the latter event we must look to our future position as that of a grandmother, because we have every reason to hope that the daughter will herself be the mother of a long succession of distinguished scientific men, able to advance the reputation of this country in respect to the construction of vessels of all descriptions. Gentlemen, the Report refers to some very important changes in the conduct of the School of Naval Architecture. One important change relates to a considerable increase of the period of time for study. Heretofore the period of study has been a course of three years, with a session of six months in each year. Hereafter it is proposed that the course of study should be spread over four years, with a session of seven months in each year. The result will be that the students in the School will have their education conducted during a period of twenty-eight months, instead of as heretofore a period of eighteen months. But this is a question rather for the decision of the Government than for the decision of this Institution. Here we have no power to regulate or determine what shall be the periods of study. But the Members of this Institution are so much interested in the subject, and are so competent to form and give opinions, that it will very much strengthen the hands of the Government in carrying out this proposed change if the result of our proceedings this morning should be an expression of approbation on our part of the recommendation now suggested by the Council (Hear, hear).

Another gratifying proof of the growing reputation of this School is to be found in the fact of the number of foreign students who continue to come to it from different parts of the world to complete their studies. It is a proof that the reputation of the School is already widely spread. Without entering further into the mode in which it is conducted, or into the circumstances of its progress, I may venture to say that this important School, in the establishment of which we took so much interest, has thus far been perfectly successful, and we have every reason to hope for its continued success and prosperity, and for its continuing to prove a permanent advantage to this country.

The Report concludes with a very important suggestion of change. Perhaps I had better read the last two paragraphs of the Report again. One is, "The Council beg leave to recommend to the "consideration of the General Meeting a rule allowing of the admission of Marine Engineers conversant "with naval architecture to be full Members instead of Associates of this Institute." Gentlemen will bear in mind that that is a very important change. It is a distinct and clear proposition. And when it is my duty to put to the Meeting that this Report be adopted, the carrying of the motion will involve the adoption of this change. That paragraph is followed by another, also of an important character and connected with it in the event of your adopting it:—"In the event of your adopting this Resolution, "the Council would suggest to you for consideration whether it might not be expedient to confer upon "the Council, as an extraordinary measure for the present year, the power of admitting as Members of "the Institution such distinguished Engineers as the Council may think proper without the usual forms "of special credentials and the submission of the names to a General Meeting." It will be for the decision of this Meeting, whether, under the circumstances and with the view to carrying out the previous recommendation, they will be disposed to entrust the Council with this power, no doubt a very

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considerable power, but limited in time to the interval between the present and the ensuing Annual Session in 1870.

I am sorry to observe that the programme of Papers to be read is not so full as usual; though many of the subjects touched upon are undoubtedly of great interest and importance. I may specially refer to the Papers to be read this morning. They embrace two subjects of very great moment. The first is Mr. Fairbairn's Paper with regard to the Law of Resistance of Armour Plates. The others refer to the no less important subject of Floating Docks. To-morrow, again, we shall have Papers from Mr. Reed and Captain Inglefield on subjects of extreme general interest; and I may say the same with regard to the Paper to be read by Mr. Grantham on Saturday morning. But although these Papers do relate to subjects of very great importance connected with the science of Naval Architecture, there are other questions of no less importance which I do not see touched upon by any of the Papers that are about to be read. And I cannot help thinking that it would be well for the Council to take some steps between this and our next Annual Meeting to effect some arrangement of subjects, so that as nearly as possible all the subjects which do interest students of Naval Architecture might be brought under consideration at these Annual Sessions.

Our duties and our studies relate, as you must all be aware, to merchant vessels as well as to ships of war. It is not for us in this Institution to presume to lay down or to determine what should be the policy of this country in the event of our being involved—which God grant it may be long before we are—in a naval war with any of the great maritime powers of the world. Of course that policy would be guided by a variety of circumstances, which it is impossible to foresee or to predict. Therefore it becomes the duty of this country to build men-of-war of many kinds, of various classes and descriptions, which might be available either for attacking an enemy, or for the defence of our own commerce and our own shores under all possible circumstances. Therefore, too, it becomes desirable that the Navy of this country should be so constructed as to be capable of being brought into action with reference to the immense extent of this empire in all parts of the world. It appears to me, that these are subjects which ought not to be lost sight of in this Institution; that in these days of change, where science is from year to year introducing novelties of endless variety in relation to the construction of ships, the manufacture of iron, and the application of steam, it would be most desirable that we should be able to consider and discuss these subjects with the advantage of the great variety of information and experience which we are able to command from various competent men.

I am happy on the present occasion to see Mr. Reed, the able Chief Constructor of the Navy, amongst us. I am sure he will not suspect me of speaking disrespectfully when I say that within the last few days we have had announced from the highest quarter novelties in the construction of powerful ships of war, which might profitably form the subject of consideration by such a body of gentlemen as are here assembled. I allude to the proposal which has been made by Her Majesty's Government to build a class of ships for the Navy such as I may say with confidence have never before been heard of. Compared with some of the armour-covered men-of-war that have of late years been constructed, they are not of overgrown bulk; being of the comparatively moderate size of between 4,000 and 5,000 tons. These ships, we are told, are to be so constructed as to draw 26 feet of water, to carry 1,700 tons of coals, and to have no masts and no rigging at all. Do not let it for a moment be

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supposed that I allude to this proposed class of ship with any intention to pre-judge or condemn it. Nothing in these days can be more imprudent than to condemn anything merely because it is a novelty. And considering the quarter from which this proposal comes, it is certainly entitled to respectful attention. At the same time there is no denying that the first impression in Parliament was one of doubt, and not unnatural doubt, I think Mr. Reed himself will admit, as to the great peculiarities of these ships. There are three important questions connected with the proposal. One is the being without masts; another is whether or not a ship without masts could be a safe ship under all circumstances; and the third is, the enormous amount of coals that these ships are naturally intended to convey. All naval men have agreed that masts and rigging, in the event of a naval action, are elements of danger, and very often found to be extremely embarrassing to those who have to command and conduct these ships. On the other hand, considering the great draught of these ships, it may be viewed as a question of doubt, how far they would be under all circumstances safe, and under all circumstances capable of escaping danger upon a lee shore. Thirdly, it strikes me there must be considerable doubt with regard to the expense that the coaling and working of these ships, if they are to keep the sea, would inevitably cause; because it would be impossible to economise the consumption of coal, as is done in all other cases of armour ships, by their being able to avail themselves of sailing power.

As I said before, I think it my duty to advert to this proposal—a proposal certainly novel and extraordinary in its character; and I do so with the impression that there is at present no Paper on the programme that fairly opens the question. I do think it very desirable, when able and competent scientific men from all parts of the country are assembled on purpose to discuss these important matters, that we should be in a position, if possible, to give some consideration to them. In the presence of Mr. Reed, I say, with sincerity, that whatever doubts I at first entertained upon the subject, are diminished by my great confidence in his ability and judgment. I hope he will not think by these few remarks that I have intended in any way to disparage his great ability or the high position to which he has so justly and so honourably attained. If he should hereafter be successful, and if these ships, extraordinary and unusual as they may now appear, should turn out, as I by no means say they will not, to be a valuable and desirable addition to our naval power, I shall be the first to congratulate him upon his success.

Gentlemen, with these few observation, I think I may sit down without detaining you further. I will, therefore, conclude as I intimated before, by moving that this Report be adopted. If it should be the pleasure of the Meeting to carry the motion, that will involve approbation of the changes which the Report recommends. Of course, it will be competent to any Gentleman to make remarks on the Report, if he should feel so disposed; but I do hope the Meeting will feel it is very desirable that any discussion on the Report should be as brief as possible, in order that we may proceed to the Papers that are to be read to-day.

Mr. CHARLES LAMPORT: Perhaps to be in order, I may be allowed to second your proposition. I do not rise to say a word against the value of the Report, or to attempt to controvert what has fallen from you, Sir, in the way of introduction. My feeling is one of regret that the Report is not more valuable. I wish to suggest to the Council and to the Members, whether the time has not come when this Association might take collective action in the way of experiments to advance our practical

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knowledge beyond the range of individual effort. We meet here to read and to discuss Papers, the result of individual experience. But we know very well, that when a man comes here to air his own idiosyncrasies, his statements do not meet with the attention which experiments made by a scientific body like this would attract. I wish to draw the attention of the Council to the fact that we have no reliable data upon which practical shipwrights and riggers of ships can rely to estimate the strength of iron masts. I believe that in mechanical science there is a great want of data with regard to the strength of wrought iron columns; and, as regards the compound strains that are brought to bear upon the masts of a ship at sea, there are not the slightest reliable data upon which a practical man can proceed in determining what shall be the strength of his masts, or in what form he shall make them. Here is a practical subject upon which the Council might use their collective influence, to suggest to, and urge upon, the Government and the Admiralty, that experiments should be made of the kind I have indicated. There is another subject to which I wish to draw attention. As practical shipbuilders we have no reliable data upon which we can determine alterations of the forms of ships in respect to the resistance of fluids upon such bodies. I believe the only data there are consist of the result of some experiments made many years ago by the late Colonel Beaufoy. Those experiments, however, do not furnish data of any value in regard to the forms of ships floating on the water.

The PRESIDENT: I beg your pardon for interrupting you. Perhaps, the Hon. Gentleman will allow me to remind him that there is a Paper to be read on that very subject on Friday evening. It is desirable that Gentlemen in speaking should confine themselves as much as possible to the contents of the Report.

Mr. CHARLES LAMPORT: I will conclude what I have to say, and limit my suggestion to the co-operation of the Council in recommending to the Government to institute experiments upon the strength of masts. The weight of masts put into ships is in some cases enormous, infinitely beyond any strain that could be brought upon them at sea. That being the case, we are subjecting our ships to a strain which is unnecessary; and shipowners are put to an expense in building these heavy masts which is entirely unnecessary. It would be of great advantage to have some reliable data by which we can reduce the strength of the mast without any fear of producing disastrous results.

The motion that the Report be adopted was then put and carried unanimously.

Mr. E. J. REED: I presume it will be taken for granted by the Meeting and by the Public that the President's remarks are not the subject of discussion. I have not the slightest desire to say one word upon your speech, Sir. I desire it only to be known that, because the President's speech is not a proper subject of discussion, I do not say anything.

The PRESIDENT: We can hardly consider the Opening Address I have made to-day a subject for discussion. But I said in that Address, and I repeat now, that my reason for making the remarks I did was, that it might be very advantageous both to you and to the Meeting that there should be a discussion of the subject. Therefore, I would suggest whether, by reading a Paper or by some other mode, the subject might not be brought forward at a later period of the Session for consideration.

Mr. E. J. REED: The point to which I should have addressed myself would not have been the ships, because that is a question for the authorities to say whether they will or will not submit the designs

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in their present state to public discussion. I should not wish to make remarks upon that aspect of the question. I quite agree with you, Sir, it should be understood by the Meeting that the President's remarks are not a proper subject for discussion on this occasion.

Since the issue of Vol. IX., the names of the following Gentlemen have been added to the lists of Members and Associates, respectively:—Colonel Michæl Ocouneff, Russian Imperial Navy; Senhor Trajano Augusto de Carvalho, Brazilian Imperial Navy, and Mr. Jamsetjee Dhunjabhoy Wadia, of H.M. Dockyard, Bombay, Members; and The Right Hon. Hugh C. E. Childers, M.P., First Lord of the Admiralty, and Messrs. Edward Johan Andersen, William John Bone, Spencer Perceval Butler, Edward Arundel Carttar, Ralph Dawson, Henry Edward Deadman, William R. Eckart, C.E., Francis Elgar, William James Fitze, William John, Joseph William Rowse, George Stanbury, R. White Stevens, John Isaac Thornycroft, C.E., A. Toropoff, and William Henry White, Associates.

During the same period the Institution has sustained the loss by death of the following Members and Associates:—Messrs. W. C. Miller and William Patterson, Members; and Messrs. John Firth and Thomas Whittaker, Associates.

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PAPERS AND DISCUSSIONS.

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ON THE LAW OF RESISTANCE OF ARMOUR PLATES, COMPOSED OF ONE OR MORE THICKNESSES.*

By WILLIAM FAIRBAIRN, Esq., C.E., LL.D., F.R.S., Honorary Associate.

[Read at the Tenth Session of the Institution of Naval Architects, March 18th, 1869; the Right Hon. Sir JOHN S. PAKINGTON, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

DURING the early stages of iron shipbuilding, I was in communication with the Admiralty on the subject of the resistance of wrought-iron plates to shot at high velocities. At that time, 1835-6, I had arrived at the conclusion that wrought iron was the safest and most durable material for shipbuilding; and I was anxious to impress upon the Government the necessity of its being employed in the construction of vessels of war. I offered to superintend a series of experiments to determine the effects of shot upon iron, provided the Admiralty would construct the necessary targets, which it was proposed should represent the side of an iron ship. On referring to memoranda and papers of that date, I find the following remarks were earnestly urged upon the Government:—

"In the event of war, it is essential that the steam navy of this country should have "great command of power, to enable the ships to manœuvre at sea with the precision of "a squadron of cavalry on parade. They should have the power to advance or retreat, "as circumstances might require; and the new system of tactics which must eventually "come into operation, would inspire the same confidence in the crew as the commander, "namely, that the iron ship is not only formidable in war, but safe under all the "circumstances of attack and defence."

At the time these remarks were made, several sea-going iron vessels had been built at Millwall, Liverpool, and the Clyde; and the application of this new material was making great progress in the different dockyards of the country. The Government, however, stood aloof, and decided to limit the construction of iron vessels to the mail and packet service. These limitations were, according to my views, inconsistent with the healthy progression which at that time was taking place in the mercantile navy, and that

* Received 15th March, 1869.

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more particularly when steam-power was becoming general in the propulsion of vessels of every description.

These were the views I entertained at this early period of iron construction; and, after several years of constant application, the Admiralty at last consented to institute a series of experiments to determine the effects of shot upon the hull of an iron ship, and also with the view of providing means for stopping the passage of water in the event of the vessel being struck below the water-line. The experiments were conducted at Woolwich, and the gun used was a 32-pounder, placed at a distance of 30 yards from the target. It was loaded at the commencement with the full charge of 10 pounds of powder. Subsequently the charge was reduced to 8, 6, 4, 2, and 1 pounds, equivalent to the effect of distance in a long or short range. In these experiments there were five targets, 6 feet square, composed of different thicknesses of plates, and variously arranged, so as to represent in effect, as also in appearance, a portion of the side of an iron ship.

No. 1 target was of three thicknesses of $\frac{1}{2}$-inch plates riveted together with double rows of rivets. Through this only one shot was fired, which made a clean hole with very little tearing of the edges; but none of the rivets were started.

No. 2 target was formed of $\frac{1}{2}$-inch plates, flush-jointed, single riveted, with frames 9 inches deep, attached with double angle irons 6 inches by 3 inches. One half of the target was lined at the back with a compound of india-rubber and cork shavings intended to catch the splinters. Two shots with 10 pounds of powder went clean through the outer skin and through the lining, carrying the splinters along with them, but the effect of the elastic cork and india-rubber lining was to close the passage after the ball, and render the openings as near as possible water-tight. The plates and bolts which held the backing were, however, much broken and seriously damaged.

Nos. 3, 4, and 5 targets, formed of double and single $\frac{5}{8}$-inch and $\frac{1}{2}$-inch plates, were experimented upon in the same way, and with nearly the same results. The experiments were conducted by Colonel Dundas, in the presence of the late Admiral Sir George Cockburn, and the other Lords of the Admiralty, and the ultimate conclusion arrived at was, that iron was not considered a suitable material for the construction of ships of war.

More than thirty years have elapsed since those experiments were made; and little or nothing was done by the Admiralty for nearly twenty years in the shape of iron constructions, until armour plates were first suggested by the Emperor of the French as a medium of resistance to the impact of shot.

Floating batteries and some few vessels were constructed with armour plates at the commencement of the Crimean war. These were followed by the *La Gloire*, in France,

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and the *Warrior* and *Black Prince* in this country, each of which were probably the first armour-plated sea-going vessels on a large scale which appeared afloat in 1860-1. From that time, when the Special Committee on Iron was appointed, there has been a constant undeviating succession of experiments to determine the strength and form of guns on the one hand, and the resistance of armour plates on the other. Sometimes the guns have had the ascendancy, and sometimes the plates, but no sooner have improvements been effected in the manufacture of plates and in the quality of the material, than more powerful ordnance have been at hand sufficient to perforate and smash them to pieces. In a few more months stronger and thicker plates would be brought forward to defeat the guns, and so the contest raged till the plates and guns advanced in a given ratio from $4\frac{1}{2}$ inches to 15 inches thick plates, on the one hand, and from the 68-pounder smooth bores to the 600-pounders on the other.

Such is a brief statement of the progress of marine iron constructions from 1836 to the present time, and having been either more or less connected with the experiments which led to these results, I venture to lay before the Members of the Institution a short extract of the experiments as introductory to the more important experimental researches—now in progress—which I hope will form the contents of my next Paper.

Shortly after the appointment of the Iron Plate Committee, guns of different calibres were employed in the experiments from the wall-piece ·87-inch bore, and $5\frac{1}{2}$ ounces weight of shot, to the 600-pounder breech loader. The experiments commenced in May, 1861, with the wall-piece and the smaller description of guns, and finished with the more powerful description of ordnance in 1864, when the Committee was dissolved.

During the continuance of the gun experiments it was considered necessary that a similar class of experiments by statical pressure should be conducted on the same plates and targets, previously experimented upon in their resistance to impact from shot. The object of these experiments was to determine the law of the resistance of armour plates, and to establish formulæ for the guidance of the artillerist and engineer. Experiments were also made on shearing, tension, compression, &c., and the results obtained shew the density, tenacity, &c., of four different specimens—cut from the armour plates—one of which was of steel.

The first series of experiments was instituted to ascertain the tenacity, elasticity, and ductility of the plates from different makers, and to ascertain what changes and improvements were required to give the maximum powers of resistance. The details of these experiments are purposely omitted in order to avoid prolixity, and the extracts from the summaries of results are alone given. Carrying out these views, the experiments commenced with those on tensile strain, as follows:—

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FIRST SERIES OF EXPERIMENTS.

TABLE I.—*On Tensile Strain.*

Approximate Thickness of Plates in inches.	Mean Density of Plates.	Mean Breaking Strain, per square inch in tons.	Mean Elongation per unit of length.	Mean Work u, for Unity of Length and Section, done in causing rupture, in ft. lbs.
$1\frac{1}{2}$	7·7471	24·453	·1769	4844
2	7·7684	25·169	·2703	7620
$2\frac{1}{2}$	7·7660	24·569	·2658	7314
3	7·7666	25·031	·2689	7538

From these results it will be seen that the ultimate elongations—indicating the degree of ductility—nearly coincide in the order in which they stand for strength, and the increase of elongation nearly corresponds with the increase of the thickness of the plates.

The coefficient, or modulus of dynamic resistance, for the different plates, given in the last column, is found by multiplying one-half the breaking strain, per square inch, in pounds, by the corresponding elongation, per unit of length, or $u = \frac{1}{2} P_1 \times l_1$.

The second series of experiments was upon compression, from which the following results were obtained:—

SECOND SERIES OF EXPERIMENTS.

TABLE II.—*On Compression.*

Approximate Thickness of Plate in inches.	Mean Ultimate Pressure per square inch, in tons.	Mean ultimate Compression, per unit of length.
$1\frac{1}{2}$	90·967	·513
2	90·967	·518
$2\frac{1}{2}$	90·967	·510
3	90·967	·511

There is a remarkable coincidence in all the four thicknesses of plates as regards the amount of compression, as exhibited in the above Table. It indicates the ductile nature of the material in its powers of resistance to a compressive strain, the specimens being reduced to more than half their original height by a pressure of 100 tons on the square

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inch; and although, in many cases, the specimens were very much cracked and distorted, they, nevertheless, did not lose their resisting powers, having sustained the ultimate weight without being seriously injured.

The third, and most important, series of experiments was that on punching. It was supposed that the resistance of armour plates to the impact of shot was analogous to that produced by statical pressure. Under this supposition, it was thought desirable to institute a series of experiments to ascertain to what extent the law was applicable to the resistance of iron plates by punching, in order to apply it to the more important experiments on impact.

The plates, in all cases, rested on a steel die block, having an opening below twice that of the diameter of the punch. All the experiments, recorded in the following brief abstracts, were on specimens cut from armour plates experimented upon at Shoeburyness, and were marked A, B, D, which referred to the makers of each. One of the plates, marked C, was of steel, and has, therefore, been omitted as being unfit for comparison.

THIRD SERIES OF EXPERIMENTS.

TABLE III.—*On Punching.*

Punch, 0·85 inch diameter; flat-ended.				
Mark on Plate.	Thickness of Plate.	Pressure on Punch, in tons.	Pressure on Punch, in tons, per unit of diameter.	Mean Pressure P_1, in tons, per unit of diameter, and Thickness of Plate.
A	$\frac{1}{4}$ inch	14·2732	16·7920	
B	,,	8·6732	10·2037	
D	,,	8·4732	9·9684	
Mean	...	10·4732	12·3214	49·2900
A	$\frac{1}{2}$ inch	25·8731	30·4389	
B	,,	25·4732	29·9684	
D	,,	22·4380	26·3976	
Mean	...	24·5948	28·9349	57·8700
B	$\frac{3}{4}$ inch	39·3804	46·3300	
D	,,	40·9806	48·2123	
Mean	...	40·1805	47·2712	63·0200
Mean value on the whole				56·7200

In the above Table we have reduced the mean ultimate pressures with the ·85-inch

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punch to 1 inch diameter, and 1 inch thickness of plate, for the purpose of comparison with the plates experimented upon with the $\frac{1}{2}$-inch punch, which had to be reduced in size in order to perforate the thicker plates of 1 inch, as shown in the results of Table IV.

TABLE IV.—*On Punching.*

Punch, 0·50 inch diameter; flat-ended.				
Mark on Plate.	Thickness of Plate.	Pressure on Punch, in tons.	Pressure on Punch, in tons, per unit of diameter.	Mean Pressure, P_1, in tons, per unit of diameter, and Thickness of Plate.
A	$\frac{1}{2}$ inch	15·4732	30·9464	
B	„	14·2732	28·5464	
D	„	14·2732	28·5464	
Mean	...	14·6732	29·3464	58·6900
B	$\frac{3}{4}$ inch	20·9804	41·9608	
D	„	21·7804	43:5608	
Mean	...	21·3804	42·7608	57·0100
B	1 inch	27·7804	55·5608	
D	„	28·1804	56·3608	
Mean	...	27·9804	55·9608	55·9600
Mean on the whole				57·2200

These experiments fully establish the formula,

$$P \propto 2rt;$$

that is, the resistance of armour plates to a force tending to perforate them varies as the diameter of the punch multiplied by the thickness of the plate, or the depth of penetration.

The values of P_1, given in Tables III. and IV., are 56·72 and 57·22 respectively,

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and the mean of these is 57, very nearly; that is to say, the general mean value of P_1, the ultimate pressure per unit of diameter and thickness, is 57 tons. Now $P = C r t$, where C is a constant, which for $2r = 1$, and $t = 1$, becomes $\frac{1}{2} C = P_1 = 57$, and $\therefore C = 57 \times 2 = 114$. Hence we get

$$P = 114\, rt \quad . \quad . \quad . \quad . \quad (1).$$

where P is expressed in tons, and

$$P = 114 \times 2240\, rt = 255360\, rt \quad . \quad . \quad . \quad (2).$$

where P_1 is expressed in pounds.

Moreover, putting U for the work expended in perforating a plate, t inches thick, with a punch r inches radius, we get

$$U = \tfrac{1}{2} P_1 \times \frac{t}{12} = \tfrac{1}{2} \times 255360\, rt \times \frac{t}{12} = 10640\, rt^2 \quad . \quad . \quad (3).$$

Formula (1) enables us to calculate the ultimate pressure in tons requisite to perforate a plate, of a given thickness, with a punch of a given radius or diameter: thus, for example, let $r = \frac{1}{4}$, $t = \frac{1}{2}$, then $P_1 = 114 \times \frac{1}{4} \times \frac{1}{2} = 14{\cdot}25$ tons. The mean value of P_1, in this case, by experiment is 14·67 tons. And so on to other cases.

Formula (3) enables us to calculate the work, in foot-pounds, expended in perforating a plate, of a given thickness, with a punch of a given radius, or diameter; thus, for example, let $r = \frac{1}{4}$, $t = \frac{1}{2}$, then $U = 10640 \times \frac{1}{4} \times (\frac{1}{2})^2 = 665$. And so on to other cases. The constant 10640 of this formula also enables us to compare the work of punching with the effective work of a projectile impinging upon the plate.

The following summary of results shews how closely the above formulæ represent the results of experiment, especially those recorded in Table IV.

SUMMARY OF RESULTS OF TABLES III. AND IV.

Diameter, $2r$, of the Punch, in inches.	Thickness, t, of the Plate, in inches.	Mean Ultimate Pressure, P, on the Punch, in tons.	Value of P, by Formula (1).	Value of U, by Formula (3).
·50	$\frac{1}{2}$	14·67	14·25	665
	$\frac{3}{4}$	21·38	21·37	1246
	1	27·98	28·50	2660
·85	$\frac{1}{4}$	10·47	12·11	282
	$\frac{1}{2}$	24·59	24·22	1130
	$\frac{3}{4}$	40·18	36·33	2543

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Another series of experiments, with a round-ended punch, was instituted for the purpose of comparing the resistance of armour plates to flat-ended and round-ended projectiles. The experiments were conducted upon the same plates as those perforated by the flat-ended punch, and the following summary gives the result of those experiments.

TABLE V.—*On Punching.*

Punch, 0·85 inch diameter; round-ended.			
Mark on Plate.	Thickness of Plate, in inches.	Pressure on Punch, in tons.	Pressure on Punch, in tons, per unit of diameter.
A	½ inch	28·1804	33·1534
B	...	21·7800	25·6235
D	...	20·1804	23·7416
B.	¾ inch	42·1810	49·6247
D	...	44·6000	52·4706

Comparing the above resistances with a punch 1 inch in diameter, as recorded in the last column, with those of an ordinary flat-ended punch of the same size, we have:—

	Resistance in Pounds.	
	Flat-ended Punch.	Round-ended Punch.
½-in. thick { A Plates ...	30·6926	33·1534
½-in. thick { B Plates ...	29·2574	25·6235
½-in. thick { D Plates ...	27·4720	23·7416
¾-in. thick { B Plates ...	44·1454	49·6247
¾-in. thick { D Plates ...	45·8865	52·4706
Mean	35·4908	36·9227

These figures shew that the statical resistance to punching does not vary much, whether the punch be flat-ended or round-ended.

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From the foregoing experiments attempts were made to ascertain what analogy, if any, existed between the perforation of plates by statical pressure and that produced by the impact of shot, or what was the difference between a steel bolt being forced through a plate by dead pressure, and a similar bolt being driven through a similar thickness when shot from a gun. The work done in the perforation of the plate is the same in both cases, but the effects upon the plate were obviously different; the punch produced a hole of the same diameter as itself, whereas the shot produced a much larger orifice and shattered the plate behind with a number of radiating cracks which seriously injured the plate. The depth of indentation could not be accurately measured in the experiments, although sufficiently correct to establish the formula which we have previously given. Before directing attention to the law of penetration, it will be necessary in the first instance to consult the following Table in reference to the depths of indentation at the point of rupture, as obtained by both the flat-ended punch and the round-ended one.

		Indentation in Inches.		
		Flat-ended Punch.	Round-ended Punch.	Ratio.
½-in. thick	A Plates ...	·10	·37	1 to 3·7
	B Plates ...	·09	·33	1 to 3·7
	D Plates ...	·08	·30	1 to 3·7
¾-in. thick	B Plates ...	·12	·37	1 to 3·1
	D Plates ...	·15	·41	1 to 2·7
Mean		·111	·383	1 to 3·45

It will be observed that whilst the statical force of punching pressure approximated closely, the indentations were very different in the two cases. In fact, the indentation with the round-ended punch was nearly three and a half times greater than with the flat-ended punch. It would appear that with the round-ended punch the ultimate indentation was equal to the thickness of the plate, whilst with the flat-ended punch it was less than half that amount.

And hence we derive the remarkable deduction, that whilst the ultimate resistance of plates to punching, under the circumstances in which they were placed in these experiments, is nearly the same, whatever the form of the punch, yet the dynamic resistance or work expended in punching is twice as great with a round-ended punch as

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with a flat-ended punch. Of course, this only approximately expresses the true law, but it offers a remarkable coincidence with the results derived by trials with ordnance, and affords an explanation of the difference which has in such trials been observed.

Taking the above extracts from the experiments, we arrive at the general formula for the resistance of wrought-iron plates to the impact of shot, as under.

The work accumulated in a moving shot is equivalent to the weight of the shot multiplied by the height through which it must have fallen in order to attain its velocity.

Putting U for the work accumulated in a shot at the instant of striking a wrought-iron plate, w for the weight of the shot in pounds, and v for its velocity in feet per second, then

$$U = \frac{w v^2}{64 \cdot 4} \quad . \quad . \quad . \quad . \quad (4).$$

If, in striking, this shot penetrate, and expend the whole of the work in effecting the rupture of the plate, U would be equal to the work causing the rupture of the plate.

The experiments on punching shew that, with a round-ended punch, the depth of penetration at the point of rupture may be assumed as approximately equal to the thickness of the plate itself. It will vary from this with different materials, being greater with the more ductile, and less with the more rigid, but in the present state of our knowledge this is the best hypothesis to make.

If, then, P be the statical punching pressure in pounds, U_1 the work done in punching in foot-pounds, and t the thickness of the plate in inches,

$$U_1 = P \frac{t}{12} \quad . \quad . \quad . \quad . \quad (5).$$

But the experiments shew that P varies approximately as the area of the metal in the section sheared; that is, as the circumference of the shot multiplied by the thickness of the plate; so that

$$P = 2 \pi r t s \quad . \quad . \quad . \quad . \quad (6).$$

where $r =$ the semi-diameter of the shot, and $s =$ the shearing resistance of the material in pounds,

$$\therefore U_1 = \frac{2 \pi r t^2 s}{12} \quad . \quad . \quad . \quad . \quad (7).$$

And if $U = U_1$, we have, substituting the value found in equation (1):

$$\frac{w v^2}{64 \cdot 4} = \frac{2 \pi r t^2 s}{12};$$

and, solving this equation for t, we have,

$$t = \sqrt{\frac{w v^2}{10 \cdot 73 \pi r s}} \quad . \quad . \quad . \quad . \quad (8).$$

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This is the general formula for the penetration of wrought iron by shot, from which, knowing the weight and diameter of the shot and the shearing stress, the maximum thickness of penetration can be found for round-ended projectiles, of such a material when the whole of the work in the shot was given up to the plate.

Cast-iron service shot are far from fulfilling the conditions stated above. Taking this into consideration, and also that the velocities at impact have not been, perhaps, exactly ascertained, it will be sufficient for present purposes to assume,

$$t = \sqrt{\frac{w v^2}{C r}} \quad . \quad . \quad . \quad . \quad (9).$$

where C is a constant to be deduced from experiments with ordnance. We can analyze afterwards the value of C thus obtained.

Application of General Formula to the Experiments at Shoeburyness.

For this purpose it is necessary to know the maximum thickness of perforation, or that thickness of wrought iron which any given shot exactly penetrates, leaving the shot with no remaining velocity. The Shoeburyness experiments give the thickness of plates perforated by each size of shot, up to the limit at which the plates resisted the impact. If the mean be taken of the greatest thickness perforated, and the least thickness which resisted the shot, in each case, this will give the nearest approximation to the maximun thickness of perforation which, under the circumstances, can be obtained.

Taking these means for each series of iron plates separately, and averaging the results, we get the following numbers:—

Description of Gun.	Maximum Thickness of Perforation in Inches.
Armstrong 6-pounder	1·286
„ 12 „	1·803
„ 25 „	2·350
„ 40 „	2·820

Substituting these values of t in the general equation (9), we get for the value of the constant C = 3,374,940. Hence:

$$t = \sqrt{\frac{w v^2}{3{,}374{,}940\, r}} \quad . \quad . \quad . \quad . \quad (10).$$

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Calculating from this equation the values of t, and placing them beside the results obtained at Shoeburyness, we have the following Table:—

TABLE VI.

Description of Gun.	Weight of Shot in Pounds.	Charge of Powder in Pounds.	Velocity in Feet per Second.	Semi-diameter of Shot.	Maximum Thickness of Perforation.		Error of Formula.
					By Experiment.	By Formula.	
Armstrong 6-pounder	6·25	0·75	1,141	1·22	1·286	1·406	$+\frac{1}{11}$
„ 12 „	11·56	1·50	1,155	1·46	1·803	1·769	$-\frac{1}{53}$
„ 25 „	24·81	3·13	1,169	1·84	2·350	2·337	$-\frac{1}{180}$
„ 40 „	40·00	5·00	1,166	2·34	2·820	2·663	$-\frac{1}{18}$
„ 100 „	110·00	14·00	1,175	3·45	...	3·613	...
Smooth-bore 68 „	66·25	16·00	1,557	3·96	...	3·470	...

Looking to the fact that the formula is merely provisional, and in some respects derived from imperfect data, the correspondence between the experimental and calculated results is sufficiently striking.

The formula applies only to cases in which the action of the shot is approximately similar to that of punching, and not to cases such as the 3-inch steel plate and the 6-inch iron plate, which broke by transverse fracture. The increase of rigidity resulting from increase of thickness, apart from any question of the ductility of the material, decreases the resistance of the thicker plates.

At present it does not appear possible to rationalise satisfactorily the constant C = 3,374,940. But it indicates that a large part of the work accumulated in the shot is wasted through the breaking up of the shot itself. Another circumstance affecting the shearing stress is the size of the fracture, which was always considerably larger than the shot itself.

Subsequently hard flat-ended steel bolts were employed, which acted more effectively in perforating the armour plates. The following formula fairly expresses the relation between the work accumulated in these improved shot, and the work expended in perforation:—

$$U = 24{,}400\, r t^2 \quad . \quad . \quad . \quad . \quad (11).$$

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and for the depth of penetration we get

$$t = \sqrt{\frac{U}{24{,}400\, r}} \quad . \quad . \quad . \quad . \quad (12).$$

where $U = \frac{w v^2}{2g}$ = the work accumulated in the shot at the instant of impact.

If the formula (10) given for cast iron and other inferior kinds of shot be reduced to the form of equation (11) or (12), it will be found that its constant is much greater, and, consequently, the effective work of the shot much less than that of the foregoing formulæ.

Now, by equation (3) giving the work for punching,

$$U_1 = 10{,}640\, r t^2,$$

and r and t being the same in equation (1), we find, by substituting $\frac{U_1}{10{,}640}$ for rt^2,

$$U = \frac{24{,}400}{10{,}640} \text{ or } U = 2{\cdot}28\, U_1 \quad . \quad . \quad . \quad (13).$$

that is, the work in the shot is more than double the work which would be expended in perforating the plate. Hence, it appears that even with this improved shot, at least one-half the work accumulated in it is lost or expended uselessly.

This waste of work is more probably due to some or all of the following causes: to the work expended in distorting the shot; to the shot breaking up a larger perforation than the net diameter of the shot; to some other injury done to the plate besides that of simple perforation; to the oscillations or recoil of the armour plate upon being struck by the shot; to the want of directness in the line of impact; or to other causes which future experiments may help us to discover. Whatever work may be taken up by the second and third causes just enumerated, such work can scarcely be said to be uselessly expended, however much it may lessen the work expended in perforation.

Another series of experiments, independent of those made at the request of the Special Committee on Iron, was instituted during the last year, 1868, for the exclusive purpose of ascertaining the comparative resistances to perforation between solid plates and those made up of two or more thicknesses in combination. These experiments are still in progress, and I hope by the next Annual Meeting of the Society to be enabled to shew the difference between a solid plate and a combination of laminated plates of the same weight and thickness, in their respective resistances to statical pressure. The present experiments are complete so far as regards the resisting powers of the solid and laminated plates to the perforation of a steel punch 1 inch in diameter. We have, however, yet to ascertain the difference which exists between the resistances of plates to rupture, when supported on a perfectly smooth horizontal disc of steel, and when

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supported on a backing or shelf of teak or dry English oak. On the completion of these experiments, I entertain hopes of being able to lay before the Society the law of resistance of armour plates to statical pressure, and to what extent it approximates, under different forms and conditions, to that of resistance to the impact of shot at high velocities.

DISCUSSION.

The PRESIDENT: The Paper having been read, I would invite Gentlemen who wish to make any remarks to do so.

Mr. JOHN SCOTT RUSSELL, F.R.S.: The result of the Paper appears to me to be this: that in regard to spherical shot, if I take a plate of the semi-diameter of your spherical shot, it is just equal to the resistance of that shot, and if I take the experimental column in Table VI. and take the semi-diameter of the shot in column 5, I see on the whole no very great deviation from that law. It seems to be the simplest possible expression of it: 1·22 is the semi-diameter of the shot, and 1·286 is the maximum thickness of perforation. If I take the next figure, 1·46, then the other, 1·803 is greater; if I take the next, 1·84, then 2·35 is greater; and if I take the next figure again, then 2·34 is the smaller, and 2·82 is again the greater; these were elongated shot. It would appear simply thus, as far as these experiments go, that for the smaller diameter, you may take the semi-diameter of the shot as the thickness of the plate, but as the diameter becomes larger, it requires a somewhat thicker plate to resist it; that appears to be the summary of the conclusions given in the Paper.

Mr. E. J. REED, C.B.: I think this Paper has a value of a peculiar kind, because if I am not mistaken it puts before this Institution the experimental results obtained by Mr. Fairbairn in connection with the investigations of the Iron Plate Committee, which investigations have up to this time been a sealed book to the Institution and the public. It is a very great advantage to the Institution that the results of those experiments, at any rate, should be made public; and they now are, in so far as these experiments go, by the presentation of this Paper to our Institution. It is rather a disadvantage in the case of a Paper of this sort that we should have to discuss it in the absence of the author, because several little points arise which he could set at rest in a moment, upon which one is necessarily in some doubt. I remember some two or three years ago, I took the memoir which Mr. Fairbairn furnished to the Iron Plate Committee, and entered a little into the examination of what Mr. Fairbairn had done, and I must say I found some curious discrepancies which seemed to me very desirable to clear up; and as these results are now before us in an unofficial form and can be dealt with publicly, I shall feel it my duty to look more closely into the facts as presented in this Paper; and if I find anything of value to lay before the Institution I shall hope to do so at the next Meeting. There are several points upon which we require explanation; one point is, that Mr. Fairbairn, towards the end of the Paper, says that among the many reasons for the results being what they are, there probably is this one, that some other injury is done to the plate beside the work of perforation. It is important to know whether these plates had or had not been fired at before the value is ascertained from specimens cut from them. There is a very great difference in the minds of Gentlemen as to the amount of structural disorganization the armour plate undergoes when fired at; and it would throw light upon this question if we could ascertain in what relation these specimen pieces stood

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to the plate and the shot fired at them. Again, one does not quite understand what is meant when he says the indentation is ·37 with a round-headed punch, and ·1 with a flat-headed. I presume the indentation is measured to the innermost point of the punch, and, if so, the comparison between the perforation with a flat-ended and round-ended punch would be very different to what the figures represent. Again, I cannot persuade myself that the first formula written down is strictly accurate; that in point of fact the pressure is entirely proportionately to either the thickness of the plate or the indentation; because it seems to me there would be very great variation in the amount of force expended in punching a plate; there would be very great variation in the amount of force exerted upon that punch during its passage through the plate. I think there would be great diminution of resistance per element of perforation in proportion as you approached the inside of the plate: in other words, when you have got nearly through you finish the work much more easily than you commence it; and this formula that P varies as $2 r t$ leaves that quite out of consideration. A large part of the value of discussions in this Institution would consist in discussing at one set of Meetings these abstruse Papers read at previous Meetings. We accept Papers of great value like the present, but we are unable to discuss them thoroughly off hand; we let them drop, and do not re-discuss them afterwards. Now it would be a great advantage to the Institution, and a real compliment to Mr. Fairbairn, if we looked forward in our arrangements for next year to a more thorough discussion of these experiments with which he has favoured us.

Rear-Admiral Sir J. C. Dalrymple Hay, Bart., M.P.: Perhaps I may be allowed to state with reference to the inquiry suggested by Mr. Reed, that the portions of plate on which experiments were made were very carefully selected, I think in almost all cases from plates which had not been fired at, or only fired at in a distant corner, where no disintegration of iron had taken place, so that the samples of plate selected for punching were perfectly satisfactory.

Mr. F. J. Bramwell: There were three things that struck me in hearing the Paper. I gathered, as Mr. Reed has said, that the experiments in punching plates showed the resistance to be directly as the diameter multiplied into the thickness of the plate. That formula puts the value of the plate to increase as the square of the thickness, on which we are all agreed. If that be so, it would seem the resistance of the plate to impact is different, very considerably different in its law to the resistance of a plate to punching. As regards the round-ended punch, it was stated in the reading of the Paper, that the work done in perforating a plate by a round-ended punch was greater than in perforating it by a flat-ended punch. In perforating armour plates by shot when there is the same amount of work residing in the shot, the shot with a pointed end does its work with more facility than a flat-ended shot; so that there does seem to me to be very considerable contradiction between the different statements of the Paper.

Sir J. C. Dalrymple Hay: May I explain? It was ascertained that where fracture did not take place—where the work of a shot was simply displacing a certain amount of surface matter, the amount of iron displaced with the flat-ended punch and with the round-ended punch was about equal, though in different forms.

Mr. Bramwell: In the compression, where it is stated the mean ultimate compression was as much as one half that of a unit of length, I should like to know under what circumstances that experiment was made,—that is to say, whether the piece of iron that was subjected to pressure was free to move sideways; because if so, that is hardly part of the condition that operates on the parts of an armour plate, which being struck by shot, are confined by the rest of the plate.

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The PRESIDENT: The practical importance of this Paper seems to me to be acknowledged by the most competent judges in the room; and I quite agree in the regret which has been expressed, that we have not the advantage of having Mr. Fairbairn here to give us those explanations which of course he would be far more competent to give. I agree in the remark of Mr. Reed upon—I was going to say the difficulty—I might almost say, the impossibility of having anything like a satisfactory discussion on a technical scientific Paper of this kind, on merely hearing it read, and then, without any further information, having to go at once into the discussion of it. It may be well worth while for the Council to consider, before another Meeting, whether it is open to us to make any fresh rule, which might enable us to discuss such questions as these with greater advantage. But I confess I fear on the first impression of the question that it would be very difficult, because, if I understood Mr. Reed rightly, his proposition would be to discuss one year the Papers of the preceding year.

Mr. REED: In further Papers.

The PRESIDENT: I thought you meant verbal discussion. If that were to be attempted it would necessitate (I do not say whether it may not be desirable) that more than three days should be given to these Meetings. The importance of these subjects, and in many cases, their difficulty, is so great that we have found how very difficult it is to get that number of Papers and that number of subjects that we wish to have, and at the same time adequately to give them verbal discussion and debate. I will now call upon Mr. Rennie to read his Paper.

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ON THE IRON FLOATING DOCK OF CARTHAGENA, ITS PROPORTIONS AND RELATIVE STABILITY.*

By GEORGE B. RENNIE, Esq., M.I.C.E., Associate.

[Read at the Tenth Session of the Institution of Naval Architects, 18th March, 1869; the Right Hon. Sir JOHN S. PAKINGTON, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

THE form of this dock may be briefly described as an oblong rectangular box or trough, without a top or ends, the walls and bottom of which are hollow, and divided into several independent chambers. (*Vide* Section, Plate I., Fig. 1.)

The vessel to be docked is placed between the side walls, and is raised completely out of water by the buoyancy of the bottom of the dock.

The side walls act as floats to prevent the dock sinking too rapidly, and eventually from being entirely submerged.

The operation is performed in this way: water is allowed to flow into the different compartments forming the base, by means of sluices, and distributing pipes; the dock then gradually sinks, until the buoyancy of the chambers, forming the side walls, becomes equal to the weight of the entire structure; that is, when it is desired to sink the dock to its greatest depth for the purpose of taking in the deepest draught ship the dock is intended for, for vessels of less draught it is only allowed to sink to a depth sufficient for the particular vessel.

The vessel is then hauled in between the walls, and the engines and pumps of the dock set to work to discharge the water from the bottom or base; when empty, it is capable of sustaining a weight of ship (less the weight of the dock), equal to the total displacement of the bottom or base.

The vessel is shored up in the usual manner adopted in the ordinary graving dock.

* Received 5th March, 1869.

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The dock is entirely of iron, with the exception of the decks, shoring steps or altars, and fenders, which are of timber.

It is strengthened both longitudinally and transversely by bulkheads, which form the divisions of the chambers, as well as by intermediate lattice framing which give the structure great stiffness.

The dock for Carthagena was commenced in 1859, sent out in pieces from England, and erected at Carthagena in a shallow basin prepared for the purpose, and when completed water was let into the basin and the dock floated out.

When first floated, it was found to have a uniform draught of water of 4 feet 7 inches, this gives a total displacement of 4,400 tons of sea water, which is equal to the weight of the dock complete.

Some of the largest vessels which it has raised are the frigate *Princessa de Asturias*, of 3,810 tons, and 21 feet draught of water, the frigate *Villa de Madrid*, of 27 feet 6 inches draught, weight unknown, the iron-clad *Sarragoza*, of 4,972 tons, and 25 feet draught, and the iron-clad ship *Numancia*, of 5,600 tons weight, and 24 feet 1 inch draught. This latter vessel remained supported for 80 days, without causing any damage to or undue straining of the dock. The weight of this ship was further tested by the depth of flotation of the dock as observed with the ship on it, this was ascertained to be 11 feet 3 inches, giving a total displacement of 10,800 tons of sea water, but on examination of the different chambers it was found that there was about $7\frac{1}{2}$ inches depth of water in the lower ones and $7\frac{1}{4}$ in the middle ones, equivalent to 800 tons weight, this added to the weight of the dock, 4,400 tons, gives 5,200 tons, leaving 5,600 tons as the weight of the ship.

The dimensions of the *Numancia*, the largest of the above named vessels, are as follows:—Length (between perpendiculars), 316 feet; extreme breadth, 57 feet; displacement at load draught, 7,420 tons.

The dimensions of the dock are as follows:—Length, 320 feet; breadth outside, 105; ditto inside, 79 feet; height outside, 48 feet; ditto inside, 36 feet 6 inches.

If the few inches of water remaining in the base and middle chambers were entirely removed, the draught of water of the Carthagena Dock, with such a vessel as the *Numancia*, of 5,600 tons weight, would be 10 feet 6 inches.

The main proportions of the dock are as follows:—The length is between 3 and $3\frac{1}{4}$ times the breadth. The width between the walls at the top is $\frac{3}{4}$ of the breadth. The

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floor of the dock is $\frac{1}{2}$ the breadth. The height of the side walls is somewhat under $\frac{1}{2}$ the breadth. The depth of immersion $\frac{1}{10}$ of the breadth.

These proportions are suitable for almost all sizes of floating docks of the rectangular form. Thus, supposing a dock to be made capable of lifting and sustaining a vessel like the *Northumberland*, of say 10,000 tons weight, the breadth would be 120 feet, the length 400 feet, the width inside 90 feet, the "floor" 60 feet in width, and the immersion 12 feet; total displacement, 16,457 tons.

In calculating the height of the metacentre, or the greatest height the weights may be raised above the centre of displacement of the immersed body at an angle of inclination, say of 10 degrees; and taking the distance between the centres of gravity of the immersed and emersed portions due to the inclination at two-thirds the total breadth, and multiplying by the portion immersed, and dividing by the total volume immersed into the sine of the angle of inclination, it will give 90·75 feet for the distance of metacentre from the centre of gravity of the volume immersed, or 85·5 feet above the line of flotation for the Carthagena Dock, whereas the centre of gravity of the entire structure and ship is calculated to be only 18 feet above the line of flotation, allowing for a ship of 26 feet 6 inches draught of water on keel blocks 4 feet in height. (*Vide* Plate I., Fig. 1.)

In the dock proposed, the metacentre is 101·5 feet above the centre of gravity of displacement, or 95·5 feet above the line of flotation, and the centre of gravity of the dock with the *Northumberland* is calculated to be only 19 feet 3 inches above the line of flotation. (*Vide* Plate I., Fig. 2.)

In calculating the amount of statical stability of the dock at Carthagena with an immersion due to the weight of such a vessel as the *Numancia*, of 5,600 tons, it is found that, supposing the inclination to be 10 degrees, that the moment of stability will be 369· when reduced to feet and tons per foot in length of the dock, or a total of 118,080 for 320 feet; and the dock proposed would have a moment of stability of 549·2 when reduced to feet and tons per foot in length, or a total of 219,680 for 400 feet. This is nearly as the cube of the breadth, and directly as the length.

Comparing this latter with a dock of a U-shaped section, with water ballast, like that actually made for Bermuda (*vide* Plate I., Fig. 3), as calculated from a lithographic drawing giving the particulars of this dock, it is found that the moment of stability equals 660 foot-tons per foot in length, or for the length of 333 feet, a total of 219,780, or about the same as the one proposed, of a rectangular form. (*Vide* Note at end.)

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A further comparison of the dimensions, weight of ship to be docked, height of metacentre of these two forms of docks, may not be without interest:—

	U-Shaped Section.	Rectangular Section.
Available length of dock for the largest ship	333 feet.	400 feet.
Extreme outside breadth	123 feet 9 inches.	120 „
„ inside „	85 feet.	90 „
Breadth of "floor"	50 „	60 „
Draught of water with heaviest ship	40 „	12 „
Area of immersed section ditto	4,000 square feet.	1,440 „
Greatest weight of ship capable of being docked	8,000 tons.	10,000 tons.
Weight of dock	8,350 „	6,475 „
Centre of displacement below line of flotation	18 feet.	6 feet.
Distance of metacentre from centre of displacement ...	38 feet 6 inches.	101 feet 6 inches.
Distance of centre of gravity from centre of displacement ...	5 feet.	25 feet 3 inches.
Centre of gravity above or below line of flotation ...	13 feet below.	19 ft. 3 in. above.
Moment of stability per foot in length of dock, in feet and tons	660.	549·2.
Total for whole length of dock „ „	219,780.	219,680.
Draught of water to take in a ship of 26 feet draught with keel blocks 4 feet in height	50 feet.	45 feet.

From the above comparison, it will be seen that a dock of rectangular form of the same proportion as that of Carthagena, will have the same total stability as the U form of dock, require about one-fifth less material for its construction, and be capable of supporting a longer ship of one quarter greater weight, and with a less draught of water.

Moreover, the arrangements for docking are less complicated; for when the ship is once on the keel blocks, pumping is the only operation to be performed, as there are neither gates nor caissons to close in the ends.

To represent the relative stability of different forms of section in a clear and simple manner (although not so accurately as may be found geometrically or mathematically), the following Table is compiled from experiments on different sections made of thin copper, to a scale of 10 feet to the inch. The models were all 9 inches long; the leverage was taken at 8 inches from the central line of the model.

The lead weights representing the ship were cylindrical, and supported on their axis, at a distance representing the height of the centre of gravity of the ship, above the floor of the dock of 27 feet 6 inches.

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A TABLE *of Experiments on the Stability of different Sections of Floating Docks, made on Copper Models. Scale of* 10 *feet* = 1 *inch.**

Form of Section.	Weight of Model in oz.	Weight representing Ship in oz.	Approximate proportion of Dock to Ship.	Breadth of Model to Scale in feet.	Height of Centre of Gravity of Ship from Floor to Scale in feet.	Degrees of Inclination with Weights, at a Leverage of 8 inches.			
						1 oz.	2 oz.	4 oz.	8 oz.
				Ft. in.	Ft. in.	Deg. m.	Deg. m.	Deg. m.	Deg. m.
A ⌊‾⌋	...	0	...	...	...	0 35	1 29	3 2	7 7
	48½	49½	1 : 1	120 0	27 6	0 52	2 11	3 57	9 6
	...	73½	3 : 2	...	...	1 29	2 35	4 35	10 6
B U	...	0	...	...	...	0 31	1 12	3 49	5 50
	42	49½	1 : 1	127 6	27 6	0 24	0 59	3 26	5 36
With water ballast ...	...	73½	5 : 3	...	...	0 21	0 55	3 6	4 14
C ⌊‾⌋	...	0	...	...	...	0 55	1 29	3 53	8 22
Without water ballast ...	...	49½	1 : 1	...	...	0 58	1 57	5 9	10 6
,, ,, ...	48½	73½	3 : 2	120 0	27 6	1 57	3 5	5 43	12 8
With water ballast ...	...	0	...	...	...	0 52	1 26	2 45	6 28
,, ,, ...	...	49½	1 : 1	...	...	1 16	2 7	3 22	8 18
,, ,, ...	...	73½	3 : 2	...	...	1 57	3 9	4 45	9 19
D ⌣	...	0	...	...	...	3 43	6 51	14 34	...
Without water ballast ...	...	73½	3 : 2	..	...	2 28	3 53	7 28	...
With water ballast ...	48½	0	...	120 0	27 6	1 43	3 23	7 24	14 2
,, ,, ...	...	49½	1 : 1	...	...	1 23	2 27	5 9	10 2
,, ,, ...	...	73½	3 : 2	...	...	1 23	2 51	5 36	10 32
E ⌊‾⌋	...	0	...	...	...	0 31	1 33	3 37	8 5
,, ...	30½	49½	5 : 3	105 0	27 5	1 26	2 35	5 43	12 15
,, ...	...	73½	7 : 3	...	...	2 11	3 2	7 7	14 48
F U with water ballast	...	0	...	...	...	6 22	12 48	...	...
	32	49½	5 : 3	80 0	27 5	9 19	14 52	...	...
	...	73½	7 : 3	...	...	7 14	12 31	...	...

In the above Table, A and B represent sections of docks, of the form proposed, and that actually executed. It will be seen on comparing the inclination of these two forms with the same weight and leverage, that B the U shape, gives greater stability per unit of length than A the ⌊‾⌋ shape, but as the model U was made by mistake to represent 127 feet 6 inches in breadth instead of 123 feet 9 inches, the relative stability as shown by the angle of inclination is somewhat greater than the calculation indicates.

* For Sections A, B, C, D, E, F, *vide* Plate I.

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The model C shews how the stability of the same form of section may be increased, by the addition of water ballast at the bottom.

The model D segmental form may, with the addition of water ballast, have nearly a stability equivalent to the form A.

The model E represents the Carthagena Dock, with its angles of inclination, and with the same weight and leverage as the other models.

Although it may be seen from this that other forms may have a stability equivalent to that of the rectangular or flat form, it can only be done by the addition of a considerable amount of water ballast, which so increases the draught of the dock as to necessitate the ends being closed in.

The Carthagena Dock, as before mentioned, was sent out from this country in pieces, and erected in a shallow basin made for that purpose, at Carthagena; this on the whole (when practicable) seems the most safe and simple plan, and the basin is moreover available when required for taking in the floating dock for the purpose of cleaning, painting or repairing.

Wooden floating docks of somewhat similar section to that of Carthagena have been towed to their place of destination, as was the Pola Dock, from Venice, the Havannah Dock, from New Orleans, and more recently, that of Alexandria, from the South of France, but the square ends of this form are no doubt ill adapted for being towed through the water.

In order to meet this difficulty, when it was contemplated to tow a dock across the Atlantic, a modified arrangement of the rectangular form was proposed by Messrs. Rennie, better adapted for being towed through the water. The side walls were to be reduced to about two-thirds of the length of the floor of the dock, the rectangular ends of the floor to have been rounded off so as to form pointed ends, upon which temporary sides were to be raised to the required height, in order that the dock might be decked over from end to end; this deck, together with the temporary sides, would have to be removed on arrival at its destination.

Considering the length of the voyage, it was thought that the empty space below the deck, might be available for the stowage of coals and other stores, to supply (during the voyage) the steamers employed to tow the dock out. This form of deck would not have required a basin as at Carthagena, and the necessary repairs could have been effected by means of a rectangular iron box lowered under the dock, and placed against the defective part, and the water pumped out from within it. The joints between the box and the bottom of the dock being previously made water-tight by means of an

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elastic substance, or the water kept out by a pressure of air, which in this case, would not have exceeded 3 lbs. per square inch.

In conclusion, it is considered that a floating dock of the form and proportions of that of Carthagena will have ample stability for the heaviest ship to be docked.

That it is of the simplest construction.

That the smallest amount of material for a given strength and stiffness will be used in its construction.

That the cost will be less than for other forms of section.

That the simplest docking arrangements and safety of the dock are best attained by that form.

And lastly, that by the modification suggested in the Paper, they may be towed with comparative safety to any part of the world.

NOTE.—A dock of the same proportion as the one of Carthagena, and of the same statical stability as the ∪ form, would have a breadth of 127 feet 4 inches, and weigh 6,000 tons for 333 feet in length.

ON A PROJECT FOR A FLOATING DOCK.*

By CHARLES H. WIGRAM, Esq., Member of Council.

[Read at the Tenth Session of the Institution of Naval Architects, 18th March, 1869; the Right Hon. Sir JOHN S. PAKINGTON, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

IN 1853 his Excellency Count Wimpfen, then in command of the Imperial Royal Austrian Navy at Trieste, anticipating that difficulties would arise, in docking the screw frigate *Radetzki* (the vessel so recently unfortunately destroyed), which our firm were at the time building for the Imperial Navy, owing to her size exceeding both in length and draught of water the capabilities of the dry dock accommodation available under ordinary circumstances at Venice and Trieste, suggested the construction of an iron floating dry

* Received 18th March, 1869.

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dock for the reception of vessels in deep water, and which, when the vessels were docked and shored, and the water pumped out, might be brought into shallower water near the arsenal, and the necessary repairs conveniently performed. Subsequent circumstances rendered it not necessary to carry out this project.

It will be seen that this arrangement involved many differences from the ordinary construction of floating docks: the draught of water of the *Radetzki*, when prepared for docking, without her consumable stores, coals, &c., was 17 feet 6 inches; and it was necessary to provide sufficient strength in the construction of the dock to meet the strain of so large a vessel at the varying draughts of the dock when filled with water, and when the water was pumped out, as well as to have sufficient flotation power for the dock in a roadstead.

With a view to obtaining the best opinion as to the strength necessary for the several parts, we consulted with Mr. W. Fairbairn, and arranged the details in accordance with his opinion.

The dimensions of the dock were proposed to be:

Length from inside of gates to outside of dock head	228 feet.
„ „ „ inside „	223 „
Breadth over all	66 „
„ from inside to inside of air cases of dock	58 „
Depth from top of floor to top of deck	23 „

By reference to the accompanying transverse section of the dock (*see* Plate II.), it will be seen that the intention was to have transverse frames or ribs, formed of $5 \times 6 \times \frac{1}{2}$ T-irons, placed back to back 1 foot 6 inches apart.

Every fourth frame or rib was to be connected, for the whole of its height, by plates $\frac{5}{8}$ inch thick at the lower part, and $\frac{3}{8}$ inch thick at the upper part, riveted to the inner rib of each T-iron.

Every second frame was to be similarly connected to the height of 12 feet, and above that height, as also the first and third frames for the whole of their height, were to be connected by plates 6 inches $\times \frac{1}{2}$ inch thick, placed 2 feet apart, being riveted to them.

The plating of the inside and outside skins was to be riveted to the ribs in the usual manner.

The plating of the outside was for 25 feet on each side of the middle line of the dock to be $\frac{1}{2}$ inch thick, thence for 8 feet $\frac{3}{8}$ inch, and above $\frac{5}{8}$ inch thick.

The inside plating for 20 feet on each side the middle line was to be $\frac{3}{4}$ inch thick, thence for 12 feet $\frac{5}{8}$ inch, and the remainder $\frac{3}{8}$ inch thick.

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Each skin would, of course, be made water-tight. In addition, there were to be seven intercostal keelsons, extending the whole length, formed of $\frac{5}{8}$-inch plates connected to the plating by $4 \times 4 \times \frac{1}{2}$ inch angle-irons.

The entrance of the dock was to be closed by gates shutting in the usual manner, with sluice valves, &c., for filling, and means for securing the gates when closed.

Pumps, worked by a high-pressure engine, would have been fixed in one of the compartments at the head of the dock for pumping out the water; and the necessary capstans, &c., for warping, and arrangements for securing were to be fixed on the deck.

On these it is not necessary to dilate.

Difficulties caused by the depth of water in the roadstead, required some modifications in the plan first proposed, and rendered it necessary to reduce the depth between the two skins, and to make additions to the other parts, to compensate for the strength that would have been otherwise sacrificed.

The total weight of the vessel, for the reception of which the dock was designed, was 2,200 tons; though this would be somewhat reduced, when in the state that vessels are, when ordinarily docked for repairs.

It would be found by calculation that in round numbers, taking the depth at 25 feet (*viz.*, that to which it was first proposed to immerse the dock), each foot run in length would be exposed to a pressure of about 10 tons, or $180 \times 10 = 1{,}800$ tons on each side; to this must be added the pressure on the gates and head $160 \times 10 = 1{,}600$ tons, or a total external pressure for both sides, and the ends of 5,200 tons.

Using the formula deduced by Mr. Fairbairn, from the experiments made prior to the construction of the Britannia Bridge, *viz.*, $W = \frac{a\,d\,c}{b}$, and taking 1 foot in length of the dock constructed as proposed, we have $\frac{9 \times 48 \times 80}{576} = 60$ tons, the resisting force for every foot in length on the sides of the dock, or in the ratio of 6 to 1 in favour of the strength of the dock, allowing ample margin as regards security.

Before concluding, I think I am entitled to remark, that the arrangements of materials here suggested by Mr. Fairbairn, for the first time as I believe, *viz.*, that of a succession of athwartship bulkheads, and intercostal keelsons, have been developed into the system of modern shipbuilding, now solely adopted in the construction of the large ironclads and similar vessels of the British Navy.

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DISCUSSION.

Mr. CHARLES LAMPORT: This question is rather one of civil engineering than of naval architecture; but looking at it from an outside point of view, I cannot but be struck with the assumed necessity to float the dock at all. We all know the ordinary mode of action is this: water is let into the dock, the dock is sunk, the vessel floated into the internal part, and sufficient water pumped out to raise the dock and the ship. The question is, why not leave the dock sunk in the position in which it is put, and pump the water out as in the ordinary graving dock? We all know there are difficulties connected with the construction of graving docks. It is necessary sometimes to provide a water-tight skin, or means by which water in improper positions should be prevented from filtering into the dock; but by having a much less elaborate structure than provided by a floating dock, sunk in a position, the basis of which should be prepared by diving, and left there, it seems to me that at least two-thirds of the expense of such docks might be spared, and that their ultimate safety would be very much better secured. Let any gentleman cast his eye on that enormous structure (Mr. Wigram's dock), and ask himself what would become of the ship or dock in case of a hurricane. I believe in the case of the Bermuda Dock, when moored at Chatham, that she dragged all the anchors that could be applied to her; and it was a question whether or not she would not be wrecked before she left this country. I therefore put the question, why not prepare a water-tight structure, sink it in a proper position, and instead of pumping out water to raise both dock and vessel, pump the water out as in the ordinary graving dock, and so carry on the repairs. Would Mr. Rennie be kind enough to say what the cost of a floating dock, such as he has described, would be?

Mr. GEORGE B. RENNIE: That depends very much on the size and locality. I cannot tell you the exact cost of the Carthagena Dock, because it was erected out there by the Spanish Government. But floating docks are not more expensive nor so expensive as solid masonry docks; and in this case it was less expensive. They found they could not, without very great expense, construct a masonry dock. It is an admirable place for a floating dock. There is a fine large basin at Carthagena; the depth of water was originally about 40 feet, and has since been increased by dredging to 50 feet; it is an admirable place altogether for a floating dock. Besides that, there are many places where you cannot construct masonry docks without vast expense from the porous nature of the ground. You may make a wrought-iron or cast-iron frame, and sink it into a hole; but you have no advantage in doing that,—you have to pay for your excavation, and to pay for your dock besides; and so if you determine to have an iron dock, the best thing is to float it.

Mr. LAMPORT: What provision is made for mooring that dock?

Mr. RENNIE: There are four capstans of the most powerful kind at either end. The *Numancia*, a vessel of 5,600 tons, is, I believe, the largest weight that has ever been lifted. Down at the Victoria Docks they have lifted vessels of 2,000 tons weight, and there is the Britannia tube, a large mass of iron weighing 3,000 tons; but I believe there is no example where by human agency such an enormous weight as 5,600 tons has ever before been lifted. The dock has lifted the *Numancia*, and it has also lifted the *Villa de Madrid* of nearly similar weight.

The PRESIDENT: You mentioned that she is now there?

Mr. RENNIE: Yes, and they are continually docking vessels.

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The PRESIDENT: I did not catch whether you stated the cost?

Mr. RENNIE: I did not state the cost.

Mr. LAMPORT: Say in round numbers?

Mr. RENNIE: The dock is constructed of about 4,000 tons of iron; and as the price of iron varies so would the cost of such a dock.

Mr. LAMPORT: £100,000 to £150,000.

Mr. RENNIE: Something of that kind.

Captain DE HORSEY, R.N.: The suggestion made by the last speaker but one, appears to deserve consideration, that before much money is spent on a floating dock, it should be considered whether a fixed dock is not far better. The question of a dock at Bermuda is of long standing. In 1851, if not much earlier, it was proposed, but a masonry dock was objected to on the ground of the porous nature of the rock. It was said that the water would flow through the rock and that it could not be kept tight, but if an iron skin were put to the bottom of the dock, it would almost appear to me the purpose could be answered. I see no reason why an iron skin should not be put to a masonry dock, instead of the expense and risk of a large floating dock like the one intended to be sent to Bermuda. It is a very doubtful thing whether that dock will ever reach Bermuda safely: it is the most difficult passage in the world to make, the wind being in your teeth the whole way. I should think taking the dock out there would be a hazardous undertaking.

Mr. RENNIE: Assuming that dock to cost £150,000, a granite dock of that size would cost £250,000. There is a shallow basin at Carthagena in which the dock was built: the basin is about 11 feet deep. When a vessel is docked, and it is required to undergo a long repair, it can be hauled on shore from the dock on to horizontal ways or slips, by hydraulic power; and by that means the floating dock with its basin will be available for seven first-class ships,—that is, two on each slip and one on the dock. That would come to a very much smaller expense than the cost of seven first-class granite docks.

Mr. JOHN GRANTHAM: We should be very glad to hear what Mr. Bramwell has to say on this subject.

Mr. FREDERICK J. BRAMWELL: As Mr. Grantham has appealed to me I will just state this. The dock to which the drawings on the wall refer is unhappily in litigation, and under those circumstances it would perhaps be indecorous for me to say anything upon it. I had the drawings placed upon the wall because I thought it not improbable that certain questions might have arisen, touching that dock, and so I was here prepared to answer them.

Mr. GRANTHAM: With regard to the dock question generally, it is one which has necessarily often been under my special notice. Though I have never built one, I have designed several and inspected a great number. Therefore, I feel a deep interest in the subject, and I think it is one that ought to engage much of our attention. It is a question generally between floating docks and those which are to be built on the land, constructed in various ways, but usually by solid masses of masonry, and involving a very great outlay. In connection with these solid docks many questions arise of very great difficulty to the engineer, such as depth of water at the shore, and so on. Viewing it, therefore, as a general

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question, I do think the floating dock is one which should receive our special attention as naval architects; and then it becomes the question which is the best plan of floating dock. Several plans have been proposed. That which has caused most interest, because it has done most work, is that which has been so ably explained by Mr. Rennie. It has been taken out to Carthagena, there erected, and has lifted many very large armour-plated ships. I believe it is the only one that has done so to any great extent; therefore we have a right to look upon that dock as one deserving our closest attention. But in addition to that, I do feel the explanation given by Mr. Rennie is one that should give us increased confidence in the work itself. It has this great advantage: it lifts the ship clean out of water, it requires no gates and no difficult machinery. It is in itself a simple structure: it requires no mechanical appliances but that simply of pumping the water out of it. This is a simple operation, and one under the control of engineers; therefore I look upon it as a simple, straightforward structure, that deserves our attention. It has a very great many good qualities: it has a broad base, and consequently, very great stability. This is a point of the utmost importance in a floating dock, where ships of great weight have to be lifted clean out of water. That dock shews a very great amount of stability. The one underneath it (the Bermuda Dock) has many peculiarities of great interest as to the mode by which the water is changed from one chamber to the other, and it is astonishing with what ingenuity the matter has been contrived so as to reduce the amount of pumping; though altogether it is not so desirable a structure as that proposed and carried out by Mr. Rennie. The one exhibited by Mr. Wigram seems to be too weak in the bottom. I suppose it has been well calculated, but the transverse beams seem to me to have a depth which is not sufficient to counteract the pressure of water which must arise in lifting the ship, and after she is lifted. Mr. Fairbairn is said to have calculated the strength, and if so, I hope it is right, but to me it appears insufficient. You will observe all the other docks have greater strength given in the bottom than that. The question is too wide to allow one to do more than to express a few general thoughts upon it. I cordially give my approval to what Mr. Rennie has done, and feel that he is entitled to our best thanks for having brought the subject before our notice. It is one which is increasing in interest every day.

Mr. Bramwell: Perhaps I may say a few words upon the subject of floating docks in the abstract. Mr. Rennie has given us, in detail, the particulars of the stability of the dock when it is raised. I think any kind of rectangular dock, when raised, and having the ship it has to dock upon it, is not likely to be wanting in stability; the difficulty is to ensure stability in the act of raising. I do not mean to say it is not secured by Mr. Rennie's dock; but I think he has been calling our attention to a time when the danger of want of stability is by no means so great as to another time, when there is a danger of a want of stability if the thing be not properly designed and constructed. I do not know whether this Meeting is aware that a floating dock was not only devised, but put to work by one Watson, a shipwright, at Deptford, as long ago as 1774;* and the kind of dock he used was, with the exception that it was made of wood instead of iron, similar to that which Mr. Wigram has put before us,—that is to say, it was a larger vessel than the one to be docked, fitted with a pair of gates at one end, this larger vessel was to be lowered, its gates to be opened, the vessel to be docked drawn in, the gates to be shut, and the water pumped out; and then the larger vessel would rise to a certain point, leaving the other one in the dry, although sunk in the water. The box dock form without gates has been for a good many years past somewhat common in the

* Sir Edward Belcher remarks that this dock, to his knowledge, was in use at Devonport, and, he believes, a similar one near Fareham, as far back as 1816.

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United States; and they propose to put gates to those docks in the event of their having to lift a very heavy ship. Some of the speakers have alluded to the desirability—if iron is to be used as a dock at all—to use it as a water-tight lining to a stone chamber, or, if not, as a water-tight dock that is not to be raised. I am sure I need not tell this Meeting if you put a wrought iron vessel 25 or 30 feet down in the water in order to put a vessel into it, shut the gates, and then pump it out, that unless that iron vessel is so properly constructed that it is capable of bearing upon every square foot of its bottom a ton of upward pressure, it will go to pieces; therefore it must not be treated as though, by putting a mere water-tight skin, you could make a dock that you could use. If you had a stone soil, true, you might line that with a water-tight casing, and pin that casing at frequent intervals to the stone, so that the water could not blow it up. But another speaker said he meant to do without an excavation; so that it is to be a vessel which when pumped out shall not float; and what is more, it shall be one capable of resisting pressure of water, which he will find means something very much more than a simple wrought-iron skin—it means a very heavy structure.

Vice-Admiral Sir EDWARD BELCHER, K.C.B.: As a seaman, I may throw some light on the origin of these docks, and why the Government is anxious to have these floating docks in preference to stone docks. In 1822 the Government sent out an engineer, a Mr. Smith, to Bermuda, to construct docks for the ships of war, and at that period, having had a great deal of experience about the stone there, I knew that it was so porous it could not possibly hold the water, and another thing, that the rise of tide being only 3 feet, any dock they built would be perfectly useless, except they sunk it to such a depth as would allow the vessels to enter, and then they would have to floor it with concrete and iron. It is evident that the Government when they turned their heads to adopt an iron floating dock at Bermuda, must have been satisfied that where the tide rises so very slightly, and where the soil is not fit to construct substantial docks, it would be much better to try an iron one. Now I am very well acquainted with Carthagena, and a dock of this description at Carthagena would answer most perfectly, because there is no chance of any hurricane or bad weather injuring a dock within the land-locked harbour at Carthagena. At Bermuda, it is subject to the same severe gales that our ships of war are; but in 1822 I suggested to the Government the adoption of one of these floating docks, very different in principle to any I have seen at present. It was to be constructed of timber, and coppered within and without, upon the principle of tanks with open bottoms, so that by forcing air down, you drove the water out of it. The whole strain of supporting the vessel was above water, and all the work that was to support the vessel in the dock was of iron and beyond the reach of being corroded by salt-water. Five or six years ago, a similar model was proposed at the London Docks, and my cousin, who happened to be Chairman of the Dock Company, asked me to see it and give an opinion as to whether it was suitable to the docks. I found that model was upon precisely the same principle. I suggested that, if, instead of using the machinery they had there at present to lift this float, they would send for a half-inch glass tube, I would raise the model out of the water with my lungs, showing that the principle of forcing air in and allowing the escape of the air-bubble beneath, obviates all the difficulty of the upward pressure upon the force-pump.

Mr. JOHN SCOTT RUSSELL, F.R.S.: I wish to say a word on this subject with reference to Mr. Rennie's kind of dock as distinguished from the other. I will call the one the platform dock, and the other the ship-shape dock. I am very glad Mr. Rennie has given us the investigation of the stability of this platform one, because many people are of opinion that a vessel becomes less stable and less able to carry top-weight in proportion to its shallowness. Now the reverse is the truth: the vessel

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liable to capsize is the very deep, narrow vessel; and the vessel not liable to capsize is the shallow, broad vessel. The form of dock Mr. Rennie has given us is a form of very extraordinary stability, and with such a breadth as he has taken we need never fear its capsizing. I may also answer a point with reference to it which Mr. Bramwell has most properly urged. He says the danger with a dock of this kind is not when the vessel is up at the top of the water, but when she is a good way down; and I think I am only anticipating Mr. Rennie's answer when I say that the very great breadth which he gives to the sides of that dock, where they rise above the platform, is itself an enormous element of stability; and perhaps I am only anticipating his answer when I say that probably the greatest merit of that particular form of dock is that it has those enormous buoyant shoulders always there, always ready to give enormous stability to the ship when any part of it is under water. Perhaps he would say that he gave this enormous—which some of us might call excessive—breadth to his dock, in order that he might have these very large and buoyant shoulders to prevent the possibility of it upsetting even when it was down at its greatest immersion, and, therefore, in greatest danger of turning bottom upwards. These, then, are the very good qualities of this dock, which give it, to my mind, very great value. The ship-shape dock I admire very much, and I think for Admiralty purposes,—I might go on to say for war purposes—there may be some advantages in adopting the ship-shape dock. There are manifest disadvantages. What I have said are the great advantages of the platform dock do not belong to the ship-shape dock; and I think we may say of the ship-shape dock that its stability has to be maintained by a good many dexterous dodges, I will venture to call them, which the platform dock does not require. That may be a disadvantage; but allow me to say in regard to the ship-shape dock that it is not unworthy of very serious consideration, and I think it is not very impracticable. I think it is very desirable to give the ship-shape dock our very serious consideration for this reason: if we are to have a naval war, which heaven forbid! or which heaven send us enterprising courage to be better prepared for than we are; but if there is to be a naval war, and if a naval war is to be—what inevitably for poor Great Britain it will be—a war carried on a great way off from home and not coming to our own doors where we are best prepared to receive it, but going to other places where we are worse prepared to receive it,—then I say that a dock or docks able to accompany a fleet to a foreign station wherever it may be, and able to take ships in for repairs, would be one of the most valuable elements in a steam fleet. Now there are plenty of difficulties, of course, in doing it, but it is to me not at all a formidable thing, and I should think Mr. Rennie would not at all think it a formidable thing to undertake to build a dock of iron in the shape of a large steam-ship big enough to take any other, not quite so large a steam-ship, into itself, and yet with two ends upon it which would make it a perfectly good propellable ship. And in those two walls or hollow sides I have no doubt there could be stored enough fuel and large enough engines to make it a very great, big, ugly, but very efficient ship, attending on a war steam-fleet. That, I think, is a point of view in which the ship-shape dock deserves our consideration. But, barring that particular view, I have no hesitation in saying that there are manifest advantages in the extremely simple platform shape which Mr. Rennie has constructed.

Mr. RENNIE: I may just mention that it is only as the dock rises that you get the total weight of the vessel upon it. That is an additional element in the stability of the dock when being raised, besides what Mr. Scott Russell says, as regards the lifting advantages of those side walls. I have witnessed a large vessel being lifted by this dock, and there is no lateral inclination of any consequence; it is easily regulated.

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The PRESIDENT: This discussion which I have heard with very great interest, has impressed me with the belief that the question of floating docks is very much in its infancy; and while it has given me this impression, it has confirmed my previous belief, that it is in itself a most important matter. It is an important matter, certainly, in two points of view; if not in three. In the first place, it is a very important financial question. We all know the enormous expense of constructing dry docks on shore. We know the immense expense this country is incurring in constructing such docks to meet the requirements of our greatly increased size of ships, and therefore it is a very interesting question, in my opinion, whether science will enable us to construct floating docks at a much cheaper rate than we can construct docks on shore. But assuming the construction of them turns out to be successful for their object, even if there is no great money saving, there is at all events the immense advantage of their power of locomotion. You may have the dock wherever you like to use it, instead of being constrained to bring the ship to the dock, wherever that dock may be. Another important consideration is, whether or not the success of floating docks will not enable you to accommodate the fleets of this country with dock accommodation, where there are physical impediments to docks at the present time. Of that part of the subject, Bermuda is a most pointed case. I have had the benefit of my gallant friend's (Sir Edward Belcher) experience, but I have always understood exactly what he has stated to us, that the nature of the Bermuda rock is such that it is next to impossible to construct a dock there, in the usual mode of constructing docks on shore. Bermuda is a most important station for the British navy; and my belief is, if we are to have a dock at all for the accommodation of the navy at Bermuda, we must have a floating dock; and it is a most interesting problem at the present moment whether the dock which the Admiralty have constructed, can, or cannot be taken out with safety and brought into actual use there. I was very sorry to hear the discouraging language of my gallant friend (Captain De Horsey), who seemed to disparage the idea of floating docks altogether, and his authority upon all such subjects is a very high one; but I do hope he may be brought to the opinion—and by experience we all may be brought to the opinion—that the power of constructing and using floating docks may be ere long established; and I think we are very much obliged to Mr. Rennie for the able Paper he has given us, combined with his very important practical experience, where, although I am afraid it does not bear much upon the question of conveying docks to their ultimate situation, it does bear in a very important degree upon the question of the practicability of using floating docks when they are constructed. Then of course there is only the question of expense. I have listened to this discussion with very great interest, and in the hope it is just one of those questions where our discussions may be productive of permanent advantage.

On taking the Chair at the Meeting on Thursday Evening, Mr. JOHN SCOTT RUSSELL said: Gentlemen, the first Paper this evening is on one of the most important subjects which can occupy our attention. For a great many years improvements in the selection and application of fuel have been subjects of study by engineers. The prospects of getting liquid fuel are, at the present moment, better probably than they have ever been. As Captain Selwyn has paid so much attention to the subject, I am sure you will listen to him with great advantage.

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ON THE PROGRESS OF LIQUID FUEL.*

By Captain JASPER H. SELWYN, R.N.

[Read at the Tenth Session of the Institution of Naval Architects, 18th March, 1869; JOHN SCOTT RUSSELL, Esq., F.R.S., Vice-President, in the Chair.]

No one here will probably be prepared to deny that economy is the order of the day, and I am here to-night to continue from last year, before the Naval Architects' Institution, the history of liquid fuel, and to insist again on the important economy to be derived from its employment in steam-ships especially. The experiments on which I was last year at this time engaged, and to which I then referred as taking place in a small steam launch, terminated in ample proof being given that they had not been unwisely undertaken by the Admiralty at the request of Mr. Reed. During a trial of seven hours forty minutes with coal, a small boiler fitted to the launch in question evaporated 5,418 pounds of water at the rate of 8·5 pounds of water (from 212°) per pound of fuel, while with oil the evaporation in the same boiler was 12·3 pounds of water per pound of fuel, and the quantity 3,370 pounds in three hours forty-five minutes.† It is to be remarked that the coal was the best navigation steam coal, and the fire was forced as much as the stoker could do it, but this was not done with the oil, because, the boiler being short, too much heat was already lost up the funnel. No more coal could have been burnt, nor could the quantity then burnt have been continued without frequent cleaning of the fires. The oil, on the contrary, was burning as well at last as at starting, and there was no deposit in the furnace or boiler-flue. The fire was lighted with wood, or wood and coal, and oil was turned on as soon as 10 pounds of steam were obtained. The steam was generally raised to 90 pounds pressure in about one hour from lighting the fire. There was no smoke, and a white handkerchief could scarcely have been dirtied in the furnace after the oil fire was put out.

The results were so far satisfactory that the Admiralty gave a larger boiler, which

* Received 18th March, 1869.

† Mean per hour:

Coal, 100 pounds	706 pounds, water.
Oil, 100 pounds	1,032 pounds, water.

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are feet.

Weight of Oil consumed per square foot of Fire-grate Surface per hour.	Mean Pressure of Steam Gauge.	Vacuum in the Funnel.	Height of Barometer.	Description of Oil used during the Trial.	Soot.	State of the Tubes at the end of the Trial.	Description of the Smoke.	Total quantity of Water evaporated in the small Boiler for use of the Jets.	Water evaporated in the small Boiler per hour for use of the Jets.		Useful Water evaporated, after deducting the Water used for the Jets, to 1 lb. of Oil consumed.		
											At the actual Temperature.	At the constant of 100°.	At the constant of 212°.
lbs.		ins.						lbs.	lbs.	Cubic feet.	lbs.	lbs.	lbs.
3·34	26	·2	29·8	Country Creosote.	Very small quantity.	Slightly foul.	Very moderate.	774	247·2	3·95	13·24	13·76	15·62

212°, instead of 16·9 lbs. as above—*i.e.*, evaporated by each lb. of oil from a normal temperature

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had formerly belonged to the *Oberon*, and sanctioned further experiments. These are still proceeding, though intermitted for a time from causes over which I have no control. I trust they will shortly be resumed. The boiler in question is nominally of 130 horse-power, and with coal has evaporated on trial in July 206 cubic feet of water per hour, making her equal, on the allowance used at Woolwich, of half a cubic foot per horse-power, to a real power of 412. On that trial she burnt in three fires 13¾ cwt. of coal per hour, and evaporated at the rate of 8·2 pounds of water per pound of fuel burnt. Now, it may here be observed that it is extremely doubtful if this rate of evaporation could be maintained for any very long time in practice with coal in this boiler. There is, on the other hand, no doubt whatever on my mind, or, I think, in that of any one who has seen the liquid fuel in operation, that whatever it does once it will continue to do for any number of hours or days, if the same quality of oil be used, and the furnace be not altered purposely, because there is no stoking needed, and no deposit of any kind to require removal. The boiler was prepared to burn the oil in the following manner: having been already placed on the wharf of the steam basin for a previous experiment not connected with these, it was only necessary to fill the tanks which were on the top of the boiler with oil, to have them correctly gauged, and to fit a pipe to convey the oil from the tank to the fire doors, where it entered the injector. Steam was taken from a small boiler placed near the large one, and fired with coal, and by another pipe this was brought to the fire doors, thence through a superheated coil in each furnace, and, lastly, into the injector, where it met the oil. The boiler was a tubular one, with twelve rows of tubes. These were divided by diaphragms in the combustion chamber and smoke box into three runs as follows: a diaphragm of ½-inch iron plate was pierced full of holes, and then lodged in the combustion chamber, over the fourth row of tubes, thus forcing the products of combustion to return through the four lower rows of tubes alone. Arrived in the smoke box, the heated air met another diaphragm, exactly similar to the first, over the eighth row of tubes, which forced it to return again to the combustion chamber through the tubes left open to it. Thence it again passed back to the uptake through the upper four rows of tubes. The object of the holes in the iron diaphragms above spoken of was, that fire clay might be plastered on the plates above and below, and be jointed through, as it was thought that the heat would otherwise soon cause the plates to lose their shape and bend down. It is clear that, had they been designed for anything more than an experiment, they should have been water spaces. But as far as the oil burning was carried, the heat seemed to be sufficiently kept down in these plates by contact with the water spaces of the boiler. No attempt has yet been made to ascertain what quantity of water can be evaporated by this boiler with oil, since it was soon discovered that the small boiler could not, evaporating from 3 to 4 cubic feet only of water, supply steam enough to burn the full quantity of oil. It was first

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necessary to find out the best arrangement of furnace, and this could be done while burning only a small quantity of oil per hour. As the size of injector, its best arrangement, and the quantity of steam required per pound of oil to produce the best effect, were also matters for preliminary experiment—these were the first points to which attention was given. It was found that the oil could be perfectly burnt, as you will see by the tabulated result, without removing the fire bars, or in any way altering the furnace so as to prevent coal being burnt the next hour if desirable. That the form of injector giving the best effects was that where the oil was in the internal injector with the steam issuing from an annular aperture round it. That the quantity of steam required for jets would be about 1 pound per pound of oil burnt. That rough broken fire brick, or whole fire bricks, loosely built up on the fire bars, were perfectly efficient as governors and distributors of the intense heat generated by the combustion of the oil. These speedily got nearly white hot, and remained so. That the superheaters should be placed in the smoke box preferably to the top of the furnace, where they had been fixed, as giving rise to the least alteration of the ordinary state of the boiler for coal. That the fire doors ought to be made in a different form, *i.e.*, box doors opening with a regulator, and hung from above instead of at the side, and that some other slight modifications would be desirable, though not necessary.

The whole arrangement was then altered in order to establish whether by lining the furnaces with fire brick after taking out the fire bars, building up bridges, &c., any better result could be obtained without any diaphragms, which were taken out.

This part of the experiment has not yet been finished, and I am not, therefore, prepared to give any further information about it now; but I hope to try it thoroughly, since it was under a modification of this arrangement, that the extraordinary results I narrated last year seem to have been obtained. The oil supplied during these preliminary trials has been analysed by Professor Church, of Cirencester College, with the following results. It is composed of

Carbon	86·48
Hydrogen	7·06
Oxygen, or refuse	6·46
	100·0

Now, referring to Professor Macquorn Rankine's admirable Paper, we find that, in order to arrive at the calorific effect in British units of heat to be expected from this oil, we have to make the following simple calculation:

	Per Cent.	
Carbon	86·48 × 15 =	13·02
Hydrogen	7·06 × 64 =	4·5
Total		17·52

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if refuse be not oxygen; or,

Carbon	... ...	...	$86{\cdot}48 \times 15 = 13{\cdot}02$
Hydrogen	... ...	...	$6{\cdot}26 \times 64 = 4{\cdot}00$
	Total	... ...	17·02

if refuse be oxygen, deducting $\frac{1}{8}$ its weight of the hydrogen. Thus, in either case we may say that the total theoretical evaporative duty or calorific effect in pounds of water evaporated from 212° Fahr. is 17 or 17·55 respectively. Now the next calculation, taking the figures from the tabulated result at Woolwich, is to be performed thus:

T_f, temp. of feed, 50° Fahr.; T_b, temp. of actual boiling point due to 26 pounds pressure, 269°; T^1, const. boiling point, 212°. Now the formula is thus:

$$\text{Evaporation reduced or corrected} = \text{evaporation observed} \times \frac{1 + T^1 - T_f + 0{\cdot}3\,(T_b - T^1)}{966° \text{ Fahr.}}.$$

Then

	T^1 212°	T_b 269°	
	$-T_f$ 50	$-T^1$ 212	
	162	57	$\times 0{\cdot}3 = 17{\cdot}1$
+	$17{\cdot}1 = \frac{3}{10}$ of $T_b - T^1$		
	$179{\cdot}1 \div 966° = {\cdot}18.$		

Then unity + ·18 = 1·18 × evaporation observed at feed temperature (14·22) = 16·77 pounds of water evaporation from constant of 212° Fahr. by 1 pound of oil against 17·52 total duty to be expected from this particular sample of oil. If other oils capable of giving up to 22 pounds or 24 pounds of calorific effect be operated on, we may expect an equally satisfactory approach to their theoretical value.

It is to be observed that the sample taken for analysis was from the last of the oil, and as we may expect that the whole quantity would be arranged according to specific gravity, perhaps this, which was one of the first trials, got a little advantage in that way, but there could not have been more difference than 1 pound of calorific power either way.

I would draw particular attention to the fact, that during this trial the temperature of the bottom of the funnel was so low as 120° Fahr. I must now point out that the rule adopted throughout the Government trials of calculating the evaporative effect from a constant of 100° Fahr., though fair enough for comparison at ordinary temperatures and pressures, does not take into account the latent heat due to high pressure in the boiler, neither does it give in any way the actual calorific effect of the fuel in British units of heat, which Professor Macquorn Rankine's formula does.

I have also to observe that in buying oil for heating purposes, as much attention

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ought to be paid to the chemical analysis showing the proportions of carbon, hydrogen, refuse or oxygen (if any), as would be done with coal to ascertain from which mine or stratum it was obtained, and consequently what effect it might be expected to produce. There will also be a necessity for a specific gravity and fire test, as adverted to in my former Paper.

I will now briefly advert to some other independent proofs of the calorific effect of these oils, as compared with coal.

A boiler plate furnace at Woolwich has been fitted to burn oil after the process patented by Messrs. Dorset and Blyth, which first converts the oil into gas in a species of retort, or still, resembling an ordinary vertical boiler of small size, and then burns it as gas issuing from small apertures in a coil of iron pipe. Here no steam is required; but I have seen reason to think that in a ship the other apparatus will be preferable, as I do not think there is much, if any, difference in the calorific results, and in the plan I now use, only the oil and steam pipes with the injector are necessary.

However this may be, the results obtained in this furnace, which now burns oil instead of coal, are briefly these:

Seventy-five gallons of oil are used per day, instead of 1 ton of coal, or, the sp. gr. of the oil being 1,050, about 780 pounds of oil heat the furnace, which had required 2,240 pounds of coal. This gives us a proportion of 1 to 2·7. But this is not all. The ½-inch iron plate, which took formerly fifteen minutes to heat, now takes six; thus effecting a saving in time, which those who have seen men waiting round a furnace for the heat to be got on, will do well to appreciate; the proportion here is 1 to 2·5. Now, 780 to 2,240 is 2·7 times the duty of coal, or equal, if we take coal at 7 pounds of water evaporative power to 18·9 pounds of water evaporated by 1 pound of oil. I am informed that a still more remarkable difference was observed in the time taken to heat armour plate when a small piece of it was tried. The heat is remarkably even and free from scale, and no difference has been observed in trials made as to the usual tests for strength after heating. Since last writing on the subject, several other boilers and retorts have been fitted to burn oil, and are giving satisfaction; but where the proper flame has not been obtained, *i. e.*, the blue glow due to burning carbonic oxide, the results always fall short of the true value of the oil, though still showing a considerable superiority to coal. As regards danger, I will repeat the experiment made here last year with a burning fusee.

But the best answer is to be given by those who have had it in practical operation during the past eighteen months without any accident. It is perfectly true that a gas explosion, though not a very dangerous one, resulting in the singeing or burning the

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faces of those who do it, can be produced, if, while there is no flame in the furnace, the oil be allowed to drop on the hot bricks till gas is made sufficient to mix explosively in the furnace with air; and I know one gentleman who has recently insisted on trying this for himself, against his engineer's advice, and who got conclusive evidence of the fact in singed whiskers and a slightly scorched face. One such explosion also took place at Woolwich at the close of a successful day's work in my absence; but there, also, those who did it confessed that it was entirely their own fault, and were not at all afraid of going on afterwards.

If I were to use any process for making the oil into gas before using it, I should prefer, on many accounts, to do this by means of Perkins's coil of hot-water pipe (used some years ago in London for baking bread), instead of putting a fire under the still.

I have now only to thank you for your attention, and to promise to give as much further information as lies in my power at the next Meeting of this Institution.

DISCUSSION.

The CHAIRMAN (John Scott Russell, Esq., F.R.S.): I am sure you will agree with me that it is very valuable to have a gentleman who will experiment upon a particular subject and who will let us know up to the latest moment what progress the subject is making. We have here several gentlemen who are thoroughly acquainted with the powers of heat. I should have said, we have some masters of caloric here. I should like to ask one of these masters of caloric to tell us, if he can, what he really expects we are to gain should we successfully substitute oil for coal as a fuel in steam navigation. Perhaps, Mr. Siemens will be good enough to say, in one or two sentences, what we may look forward to—what advantages he expects we may reap, whether any and to what extent.

Mr. CHARLES W. SIEMENS: As the Chairman has called upon me, I may say I go so far with the author of the Paper, in the able manner in which he has put it forward, that in burning a fuel, a hydro-carbon, such as oil is, we may expect very superior results to those which we obtain from evaporating water by carbon or ordinary coal. No doubt, the calculation which Captain Selwyn has put before us is the correct one, according to the best facts with which we are acquainted. Only I would observe that if the 6·46 per cent. of non-combustible matter in the oil is oxygen there should be a tare allowed on account of it.

Captain SELWYN: I think I gave that.

Mr. SIEMENS: It appeared to me that Captain Selwyn did not make any distinction between oxygen and mere foreign matter.

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Captain SELWYN: I took both cases, and I gave you the result of both cases.

Mr. SIEMENS: Well, in the case of oxygen, of course combustion takes place without generation of heat, inasmuch as the fixed oxygen in combining with fixed carbon produces a gaseous compound, carbonic acid, without generating heat at all. Therefore, for the equivalent of the oxygen, carbon ought to be taken off the result. It may be asked, why should oil give such a superior result to coal, which, if you analyze it, contains very often not more than 6 per cent. of foreign matter. I think an explanation may be attempted in this way, that in burning coal we feed the furnace in an exceedingly irregular manner, charging the grate at one time with an excess of hydro-carbon, which flies off and finds an insufficient amount of oxygen in the atmospheric air that enters the grate to burn it; and at other times the air that rushes through the grate has not time to take up its equivalent of carbon to produce carbonic acid. The result is, that in examining the products of combustion of an ordinary furnace, we find as much as 25 or 30 per cent. of pure oxygen on one hand, and we find a considerable amount of unconsumed carbonaceous matter going into the chimney along with it. This must be attributed not only to the unequal feeding of the coal into the grate, but it must also be attributed to the cooling effect exercised by the boiler, in checking combustion before the chemical action is completed. The first consideration in constructing a suitable grate ought to be to maintain the temperature of the flame for a sufficient length of time to complete the chemical action between the oxygen and carbonaceous matter. That, no doubt, can be obtained in a much more perfect manner in dealing with a liquid fuel like oil. This liquid in itself would be rather difficult to deal with, inasmuch as the surface it presents in the liquid state to the oxygen of the atmosphere would be very limited; but in blowing it in, as Captain Selwyn does, by a jet you get an extreme subdivision of the oil, and in consequence you may obtain a perfect combustion. From the results brought before us by Captain Selwyn, that seems to be the case; we get an extremely perfect combustion, and, therefore, we get an extremely great duty performed. The practical question then arises, what are our sources of supply of this oil. I do not know whether the author of the Paper has gone into that point, but it is a question of very great practical importance. As long as we have liquid fuel there can be no doubt that, weight for weight, it is superior to solid fuel. These heavy oils are free from the great objections that apply to light hydro-carbons, on account of their volatile qualities. But the question with me is, whether we can obtain such a supply of heavy oils at a moderate cost as will justify their employment upon a large scale: for instance, will justify their application to our marine boilers.

Mr. OLIVER BYRNE: The present plan of arming ships with thick sheets of metal, and sending them to sea with only two days' consumption of coal, is useless. The country that builds ships on Mr. Reed's plan, like the last ship, which could only go a day out and never come back again, ought to have something better than coal. Why has there been so much delay in the application of liquid fuel by the authorities?

Mr. E. J. REED, C.B.: I can assure the Hon. Gentleman that I am very glad to have this opportunity to dispel the delusion into which he, among many others, has fallen, respecting the coal supply of our ships. I do so the more readily, because I am perfectly certain that the author of this Paper is the very last person who would wish to have the use of liquid fuel promoted by misrepresentation and error concerning solid fuel. Now there is a most singular delusion respecting the capability of our steam-ships

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steaming on their coal. I must confess that to me, of all the delusions that I have had the pleasure of making acquaintance with in connection with naval affairs, that about the power of our ships to steam for one or two days only, is the greatest. It is a very popular one, but it is not the less incorrect on that account. In the case of the last ship to which Mr. Byrne referred, as being capable of going out for one day and never coming back again——

Mr. BYRNE: I said two, not one.

Mr. REED: This Gentleman said, for I took the words down at the time, "That the last ship could only go a day out and never come back again." I cannot allow him to go back from that position. If you will allow me, I shall be able to shew you how very erroneous that view is. I hope it will not be supposed that I am addressing myself to one individual in the Meeting, but to the Meeting generally, and dealing with a question of public interest. The coal supplied to the recent armour-clads is 600 tons. I shall not undertake to say for how long a time any ship can go at measured mile speed, simply because it is utterly out of the power of the stoking staff of any ship to go at measured mile speed for days together. But I may say this, that the consumption of coal per indicated horse-power, on the six hours' run of the *Hercules*, recently, was below 3 pounds per indicated horse-power per hour. I may also say that the average consumption upon the voyage of the *Serapis* troop-ship, has been 2¼ pounds per indicated horse-power per hour, throughout the seasons that she has been running; and the average consumption of the *Crocodile* has been 2¾ pounds per indicated horse-power per hour. I am going to assume for the moment that the *Hercules* is required to steam, not at an unreasonable speed, but at the reasonable speed of 12 knots, which I think you will say is a very considerable speed for a ship to sustain over a long period; and I will assume that she burns not 2½ pounds, but 3 pounds of coal per indicated horse-power per hour. Now, the *Hercules* steamed 12 knots, at about 4,000 indicated horse-power; therefore, the first step in my argument will be, that she will burn three times 4,000, which is 12,000 pounds of coal per hour, in steaming at 12 knots. Now we require to multiply that by twenty-four hours to get at the consumption per day; and if we divide the total by 2,240, it will give us the quantity of coal in tons per day. Anybody will find that 600 tons is equal to about five days' consumption, steaming at 12 knots. This will shew you that the *Hercules* can steam at 12 knots for five days of twenty-four hours, consecutively; and I must take the liberty of saying that that is an extraordinary speed for ships to sustain over a long period; and if she is to make a passage without the extreme pressure which persons who are not responsible for her sometimes require, you will find that she is able to steam at a moderate speed for a very long period indeed. The notion that these ships are unable to steam for more than one or two days at full speed is not a valid one; is not a sound one. There can be no doubt that at extreme speed—which alone a ship would be driven to make if she were pursuing an enemy, or under some other emergency—a ship could steam for five days; but for all ordinary purposes these ships, and the whole of our iron-clads, can steam for ten or twelve days at a very fair speed indeed. I may also say that it is extremely erroneous, in considering the fuel supplies of our recent iron-clads, to imagine that 100 tons of coal represents with them the same thing as 100 tons with the former iron-clads; because the recent ships all carry engines weighing a ton per horse-power, with their economising superheaters and surface-condensers. They carry per nominal horse-power one-fourth more than the old engines; consequently, it is only fair to give them the benefit of that in comparing their supply in tons with other vessels. So much by way of digression from the subject of Captain Selwyn's Paper. The only part I had not the advantage

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of hearing was the beginning of the Paper. I am quite prepared to tell Captain Selwyn the reasons for these experiments being suspended. I do not know what he said in the early part of his Paper. I am sure he did not say anything that was not proper and considerate; but I believe myself that there is absolutely no impediment in the way of the pursuit of the enquiry upon which Captain Selwyn has so ably entered, except the fact that the navy does not primarily exist for experimental matters. It has other things to do; and such experiments as the Admiralty are pleased to sanction and carry out, must be subject to the convenience of the Admiralty, and to the opportunities which the Admiralty are able to place at the disposal of the experimenters.

Mr. F. J. BRAMWELL: I do not see here Mr. Crampton, who I had hoped might have been present, and who could have brought before this Meeting something which I think would have been suggestive in reference to Captain Selwyn's Paper. It is not about the use of the liquid fuel of which we had from him a most detailed and interesting account last year; it is a method of dealing with solid fuel in a way approaching to liquidity, which proves as it were the usefulness of dealing with liquid fuel, if you can get it in sufficient quantities, at a proper price, and of a safe kind. That is to say, that Mr. Crampton has for some months past been experimenting with extremely useful results upon coal divided into the smallest possible dust. The nearest approach that you can have to liquid is, of course, a very fine powder, where the surface of the particles in proportion to the bulk is very large. With a liquid the surface may be infinitely extended, according to the nature of the implement you use for projecting the liquid into the fire. As Mr. Siemens says, by using a jet you get the surface extended, and in that way you get perfect combustion from a fuel which in its constituents is very little removed from coal. That has been carried out recently by grinding coal into a fine powder, and in the state of powder introducing it by a blast into the furnace; and getting therefrom a result by no means so high as that we see here obtained from liquid fuel, indeed, nor above two-thirds of the amount; but a result, looking at the quality of the coal employed, considerably greater than that given by what is called good large coal. This is not only not large coal, but it is small coal made a great deal smaller. I think that goes to show that the reasons given by Mr. Siemens, who if he does not know everything, knows everything relating to heat, for the great superiority of combustion of this liquid fuel over solid fuel having the same constituents. I thought it might be interesting to state that to the Meeting. I should like to ask Captain Selwyn, if he did not refer to it in the early part of his Paper which I did not hear, to state now what means are provided for regulating the admission of air in proportion to the liquid fuel, because, of course, the very efficiency of combustion depends upon having a proper mixture. Anything too much, or anything too little, to a certain degreee diminishes the effect of combustion. It appears by that diagram of Captain Selwyn's that very nearly the perfection of combustion has been obtained; therefore, I should like to know whether that is a mere matter of skill in the man who manipulates the fire or whether it is accident, or whether it is something that has not been disclosed, a matter of experience, or a matter which you can teach to any man, and make certain that he will observe within reasonable limits.

Mr. CHARLES LAMPORT: Will Captain Selwyn allow me to ask him a question or two? First, whether the cost of the liquid fuel is not twice as great as that of coal, weight for weight;—that is, what may we consider the cost of oil to be, put in fair competition with coal? Next, whether the coal that was used was the Dufferin coal—that which is recommended by the Admiralty as being the best? Next, whether the boiler for the combustion of coal was one similar in all its concomitants

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and accessories, to such a one as Mr. Reed would put in his latest launched iron-clad, with superheaters, and every other advantage of that kind? Next, whether or not, in the case of oil being explosive at a temperature of 240°, which I think I gathered from what he said——

Captain SELWYN: No.

Mr. LAMPORT: Combustible at 240°?

Captain SELWYN: Combustible at 240°.

Mr. LAMPORT: Then, perhaps, he will tell us at what temperature it becomes explosive; because we all know that some very serious conflagrations have taken place, and that those conflagrations have always been attended sooner or later by most disastrous explosions. And whether or not in the case of a fire at sea, provision could be made on board a steamer of such a nature as to diminish the risk of explosion? As to its specific gravity, as shown by the mixtures on the table, we all know that a lecturer can make experiments where cork shall sink and lead swim.

Captain SELWYN: There is nothing of the kind here. You cannot put the oil in water without its going to the bottom.

Mr. LAMPORT: Do I understand from that, that all the component parts of that oil are heavier than water; that no part of it will swim on the top of water; that if it is stirred up with water, the compound will again sink to a state of rest? If Captain Selwyn will kindly answer these questions, I shall be exceedingly obliged, being interested in steamship propulsion and in the most economical combustion that can possibly be devised. My last question is, whether or not, with these marvellous results, there is any practical working going on in any regular manufactory or workshop, or otherwise, so that the public may satisfy its curiosity?

The CHAIRMAN: There are some Gentlemen present who have been using the oil; perhaps they will give us the results of their experience.

Mr. LEWIS OLRICK: It may, perhaps, be interesting to the Meeting, as I have put up a number of these furnaces, to give the practical result of what has taken place. The boiler which I have generally applied it to is the Cornish boiler. It is the system that is shown in the diagram as applied to a marine boiler, the so-called Aydon System, which derives its name from the inventor. The system is applied almost in a similar manner to what you see in the diagram; there is the injector, taking the steam from the front of the boiler, either carried through the superheater arranged in a similar manner just in front of the fire, or taken from the boiler direct into the injector. The oil is taken from a reservoir generally placed outside the wall of the boiler house, so as to comply with the rules laid down by the insurance companies. I may say that about twelve months ago the insurance companies prevented my putting up these furnaces, and even compelled me to take away liquid fuel furnaces in several places; but in the very same places the insurance companies have now allowed those furnaces to be replaced, because after due examination they have found that they are perfectly harmless. I have been asked several questions regarding the practical application of the furnaces, and I shall be happy to answer some of those questions. In respect to the burning of the liquid fuel there have been several imitations of the system called Aydon's System; and in some of these cases the furnaces have been taken away again, because they gave very little better

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result than by burning coal. But in all the cases that I have had to deal with, they have given satisfactory results. Out of three Cornish boilers, say 25 or 30 horse-power boilers, 6 feet diameter by 30 feet long, I have been able by the application of the liquid fuel to save one boiler and do the same work, to save entirely one boiler, and the expense of burning liquid fuel instead of coal has been considerably less. I regret exceedingly the absence of one Gentleman, who has had the apparatus at work in his place, and who promised to be here to-night; because I should like you to hear from his mouth instead of mine what he has saved himself by the use of liquid fuel. The question of danger is a very ordinary question among people who know nothing whatever about liquid fuel. They generally call it petroleum. It is the greatest mistake that can be made. I would never advise you to burn petroleum, or any light oils like petroleum. But if you burn oil of a specific gravity of not less than 10·4, that oil of Captain Selwyn's is 10·5, there is no danger. I was requested the other day to go down into the country where a furnace had been put up, because they had met with one of those accidents that Captain Selwyn mentioned—there had been an explosion. I had sent down strict instructions how to light the fire. The engineer burned it very satisfactorily. The principal happened to come in, and against the express wishes of the engineer proceeded to burn it in a different manner; and as it did not light with flame, the consequence was gas was instantaneously produced and collected in the furnace, and when the gas came down low enough to the fire of course there was an explosion. The gentleman was thrown 5 or 6 yards over into the coal bunker, and his whiskers were singed. I never had my whiskers singed, because I never did anything but what I knew it was correct to do. I asked him before I went down if he considered the gas-burner in his office dangerous, he said, "No." I said, "If you leave it turned on "for a considerable length of time, the gas will fill the office, and then if you come in with a candle you "will have an explosion." It will be the same with the liquid fuel, if you let the gas off and then come upon it with a light, there will be an explosion. If it is used in a proper manner there is not the slightest danger. The rule has always been to apply the apparatus without the slightest alteration in the furnace at all, so that at any moment when you were out of oil, or oil should so rise in price that you could not afford to burn it, you could fall back upon the use of coal. For instance, in the place I mentioned that I went down to the other day, in the presence of those who were afraid of it, I started the furnace immediately with coal. When it was burning with coal I started it with oil, and in about an hour's time we burned nothing but oil. And although there were only two boilers, 6 feet diameter by 30 feet long, we depended almost entirely upon one boiler. The damper of the other boiler was entirely shut and the fire remained in it, but it was not stoked for four hours and a half. Of course, the fire remained dead in the furnace, so that at any moment you could lift the damper, and could burn the coal fire again. For four hours and a half we depended upon the liquid fuel furnace. That is rather a better result than I should like to state to people, because as a rule they would not believe it. Captain Selwyn—and I am sure you have confidence in him—would not testify to anything that was not correct. I do not know whether Dr. Paul, who has read several Papers on liquid fuel, is present. What I am about to say is only to prove to you how fairly one can go wrong. In April, 1865, Captain Selwyn read a Paper before the United Service Institution, and there during the discussion Dr. Paul stated that it was impossible for hydro-carbon or for liquid fuel to be equivalent to coal. In 1868, he read a Paper himself, and I shall now quote from the Paper. He says, "The evaporative efficacy of this material as compared with coal "would not reach the above limit of 40 per cent. in excess." There Dr. Paul has given it 40 per cent. above what he stated previously. Next, in a Supplement to the Paper, written afterwards, he states,

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"In order to complete the comparison between this material and coal as fuel for steam vessels, if the "average duty realised with coal on board ship be taken as equal to 7lbs. of water heated to 60°, and "evaporated to 212° Fahr., the maximum effect of the oil might be about 100 per cent. greater than that "of coal as now ordinarily used." I wish to know how far Dr. Paul will go. According as we prove by hard facts in practice what is the case, Dr. Paul advances upwards; but I have always been under the impression that theory should teach us first, then practice ought to follow. When I had the honour to address you the last time I stated certain facts, and I added that they were simply hard facts which could not be got over. There is no doubt there are many things that are correct in theory, but they meet with difficulties in practical application. Therefore, we always find that we can never obtain so much in practice as we ought according to theory. That point has been satisfactorily explained to you by Mr. Siemens.

The CHAIRMAN: Any more facts?

Mr. OLRICK: There was a question asked by this Gentleman about the price. The ordinary price of liquid fuel produced here, in London, is 17*s.* 6*d.* per ton. That is as near as possible the same price that coal is; but the effect is different. You get at least 50 per cent. additional useful effect, and sometimes double the effect from liquid fuel. In conclusion, I will mention to you a fact. A factory has now been burning liquid fuel for eighteen months. They had two boilers fitted with Galloway tubes; those two boilers were not capable of driving the factory. They were just going to order another large Galloway boiler when the liquid fuel was introduced to them. The result is, that, after some practical difficulties for a month or two, they now burn it in the larger boiler only, with sufficient steam to drive the whole of their factory. But the larger boiler required some repairs in the shell a little while ago, and the proprietor was afraid that the small boiler would not be able to drive his factory. I said the only thing you can do is to try it. We tried it, and found that with a sacrifice of three gallons of oil per hour we could supply the factory with sufficient steam. But the large boiler can keep sufficient steam to supply the factory which the two boilers could not do before.

Captain SELWYN: In answer to the questions which have been asked, I must first take Mr. Siemens. I must observe that the very first objection that met me in 1865, when I began to advocate the examination into the use of the liquid fuel—for I am neither an inventor nor a patentee of it—was that we could not afford to alter our boilers. It has been my business to prove that, without alteration, and with a very simple arrangement of furnaces, the same boilers could do the work. I have not sought for the best type of boiler, but I have sought for the very worst, and backed the oil against the best coal. I have no doubt on my mind, that when you get better duty out of coal, you will in the same boiler get better duty out of any substance whatever. Whereas, we have never succeeded in getting more than 10 pounds of water evaporated with coal out of a theoretic value of 15 pounds, we have at once leaped to within less than 1 pound of the whole theoretic value of our material here, *i.e.*, 17·5 pounds, and that with inferior appliances. Of course, I quite agree with what Mr. Siemens has said with regard to the oxygen and hydrogen combining to form water, and the consequent loss of a certain portion of the duty of hydrogen. I have given that, and it will be found in the Paper whenever it attains the dignity of insertion in the Volume of Transactions. As to the sources of supply, I have very closely considered that question; and I say the effect of burning this material will be as follows:—the whole of the bituminous coals, wherever existing, will be raised in their calorific value to the level—indeed, above the level—of the best anthracite. Those who

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know what are the sources of supply of bituminous coal in Europe, as compared with those of anthracite, will best understand how far that will affect the two interests. I say there is not a ton of slack coal produced at the pit's mouth, and thrown aside as refuse, that cannot be turned into oil on the spot, that cannot be made into condensed fuel, and sent away as condensed fuel. I need not tell you of the saving of transport with such a process as this, besides the fact that we can make use of a waste material—a material that has never been employed as a calorific agent at all—where the oil-producing substance is blue shale and mud. I have accurate records of the quantities of oil obtained, per ton, from each of these descriptions of coal and shale; and I am quite sure the question will only be one of price, as all these things are; and, as the Navy and the commercial marine can afford to pay best for this fuel, they will for a time have a monopoly of it. To them it is of more importance than to any manufacturer, except perhaps to the metallurgist, to whom it is of very large importance, owing to the absence of sulphur and phosphorus, and to the facility of getting equal heat throughout. But the result will be that the Navy will have the first advantage up to a certain point, where the results are comparable with coal; and there it will stop, and the persons who hold it will cease to ask a higher price. Mr. Byrne asked me the reasons for delay. I adverted to that in my Paper, and said the matter was not under my own control. I have only to answer that question by saying that with all the economies we have heard of recently, the economy of time has not been sufficiently studied. Mr. Bramwell spoke about the other process of using comminuted coal. I know the value of comminuted coal; I know perfectly well how necessary it is that oxygen should be brought into contact with every particle of a burning fuel. I know that this can never be done with the most careful stoking in our ordinary way of applying coal in a grate, and that it can be done a very great deal better when the coal is pounded into dust and blown in. But that does not get rid of the question of bulk. The process rather increases the bulk. Comminute your coal, put it on board ship, and I need scarcely tell you that you would not find your power of carrying fuel increased, or the coal more easy to handle. Getting space for and trimming coals are sufficiently difficult operations as it is; I do not know what they would be if we got the coal in dust. The regulation of the air supply does not necessitate any great change in the arrangements. If the fire door be of that description invented by Mr. D. K. Clark, it is quite sufficient to give us that which we seek for, the carbonic oxide flame. When I see a brilliant white light in a furnace, I know I am throwing away my oil. Though every part of it seems to disappear and ought to give out its heat, still it combines with half the proper supply only of oxygen, and does not combine with the other particles that it is capable of taking up. Therefore, I seek for the carbonic oxide flame,—I seek for that blue flame which is essential to the proper combustion of the oil. Under this, the fire brick with which the furnace is lined, or which is piled on the fire bars, gets white hot, and maintains a constant regulation of the heat; which does not admit of any of those changes going on in the air supply, which we have to lament with ordinary furnaces. Mr. Lamport first asked a question about the cost. Now the cost, as far as I have been able to obtain it, varies from one halfpenny a gallon to three halfpence, and up to twopence. It varies according to the idea that people have of its value. I cannot expect—nor do I think any reasonable man can expect—that when such a calorific duty as that we have seen is to be got out of this material, we should ask people to sell it for less than its value. Whatever that value may be, it will reach it. The next question was,—what coals were used in the trials? The coals used during the trials at Woolwich were the best steam navigation coals. I cannot say whether they were the Dufferin coal, but they were the best sample of coals. Another question was,—at what temperature is the oil explosive? The oil is never explosive: the gas which arises from it is

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explosive if you bring it up to 560° Fahr., and make it give off that gas. It will not become gas under a temperature of 560° Fahr. The gas given off is not itself explosive; it is explosive only when confined in a small chamber and mixed with from nine to thirteen parts of atmospheric air, neither more nor less. It will light otherwise with a quiet flame. The specific gravity which I showed here ought, I think, to give a perfect answer to the question, whether it will mix with water. The specific gravity of the oil, substantially, is over that of salt water, and it could be increased even further at will. Next, as to the practical use of the fuel, the last question Mr. Lamport put, that is answered by this. One set of works have been entirely driven with it for the past eighteen months, as stated by Mr. Olrick. A second set of works has been erected within the past five months for the purpose of distilling tar; there it has been used with such success that the manufacturer works off his stills in half the time he did before. At Woolwich dockyard a gentleman can tell you that he has been using it, practically, for bending the boiler plates of furnaces, with very great satisfaction to himself. Other furnaces are fitted all over the country; and in connection with it we find no difficulty when stokers will obey our simple orders,—never to put oil into the fire while the fire is hot—while the bricks are hot—without having a flame in the furnace, that is to say:—they can get a flame by throwing a few shavings into the furnace. If the temperature is such as to make gas without any flame being present, and they allow that gas to mix with a proportion of air, and if a flame is then introduced, it partakes of the nature of an explosion. What it will do when it explodes is like the result of an ordinary hot fire of coals suddenly loaded with slack. Gas is then made, which mixes, in many cases, with air; there is a shot back, and then the mischief is over.

Mr. LAMPORT: I also asked about the boiler in which you tried the oil.

Captain SELWYN: The boiler was actually a sister boiler to one of those fitted in H. M. S. *Oberon*, and it had all the appliances which are in use in a man of war except a hot feed. It was a common marine boiler. What might be the result of a very improved boiler, I am not at all able to say. If you do get a better result from the coals, then we will shew you a better result from the oil.

The CHAIRMAN: I am sure you will all agree with me, that we owe our very cordial thanks to Captain Selwyn for the excellent Paper which he has given to us. I am sure we all understand combustion a little better than we did before, from the luminous exposition we have heard. We now know that you have nothing more to expect from oil in reference to its chemical constitution than so much carbon in the shape of fuel. But in this liquid shape it is on its way to the gaseous shape. In Mr. Bramwell's form, it is also on the way to the gaseous shape, but it has not gone quite so far; it is in the shape of little solid atoms, which are a very good preparation for the gaseous state. Now then we have become acquainted with carbon on the way to become fuel in the liquid state, and in the powder state. I think Mr. Siemens has given us the true theory of any economy there may be in using one rather than another of these states of fuel, in saying that it depended upon the degree of accessibility of the carbon to combination with the oxygen of the air, whether the one fuel burned more completely and readily than the other, or less completely and readily. We know now, I think, the merits of the question; the merits of the question I think are shortly these: If carbon—coal, slack, anything you please to call it—can be comfortably got into the liquid shape without greatly enhancing its price, beyond that of solid carbon, and if it can be conveniently obtained with that particular density which gives it more safety, and if the safety arrangements can be rendered such under water, which I dare say they can, that the liquid will remain

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perfectly safe, then there will be but one difficulty more, and one question more to be answered. "Are common stokers and engineers sufficiently skilled, intelligent, and well educated to be entrusted with this chemical laboratory?" If they are, or when they are, then we may safely embark upon the use of liquid fuel. I think these are all the difficulties before us, and I think we are all in a position to form our own judgment on this subject.

Captain SELWYN: I do not know which of the Gentlemen who joined in the Discussion asked me about the engineers. I can only answer that question by saying, there is no difficulty whatever. We took no highly-educated man whatever. The ordinary stoker does the work, and he does it to his entire satisfaction. As soon as the blue flame is produced, which he obtains with a touch of the finger, he has nothing further to do with the boiler till he puts the fire out.

[The Chair was then taken by Vice-Admiral Sir Edward Belcher, K.C.B.]

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ON RAILWAY COMMUNICATION ACROSS THE SEA.*

By John Scott Russell, Esq., F.R.S., Vice-President.

[Read at the Tenth Session of the Institution of Naval Architects, 18th March, 1869; Vice-Admiral Sir Edward Belcher, K.C.B., Vice-President, in the Chair.]

One of the great unsolved problems of modern engineering is, to complete the wanting links of European railway communication, by joining Dover to Calais. That is the missing link in the unity of European civilization. It is also the missing link in material commerce. Railway trains, laden with the wealth of nations, run smoothly down to the banks of the sea on either side, and are there abruptly stopped,—rudely broken up, their contents strewed over the quays, craned and laden into ships, uncraned and unladen on the other side, again stowed in wagons before they can continue their second railway journey,—and thus, on a short sea gap of some twenty miles, endure more delay, undergo more wear and tear, and cost more money, than on a hundred miles of railway.

That which is merely wasteful and costly in the transport of material merchandise, becomes degrading and barbarous when applied to human beings. The transport of civilised men and women between the kingdom of Great Britain and the empire of France is disgraceful to two cultivated nations. The traffic of human beings between Calais and Dover frequently exemplifies some of the worst features which have been pictured of the African slave trade. We are told of one hundred and fifty negroes huddled under the decks of a ship where they have not even room to lie down—where the air is pestiferous—where they are willing almost to throw themselves overboard to escape a state of existence that has become intolerable. What we have *seen* between Calais and Dover is, a hundred, or a couple of hundred, civilised persons, citizens of refined communities, systematically huddled under decks, where there was neither room for comfort, rest, ventilation, cleanliness, nor health. We have seen fifty delicate, refined women crammed into a cell just large enough to allow them to sit jammed together on the floor. Shortly before starting, a benevolent stewardess placed on the knees of each a convenient basin, and, a few minutes later, an anxious husband, descending from the

* Received 23rd March, 1869.

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wet deck to inquire after the welfare of his delicate wife, found it hard to endure the close, confined atmosphere, to which, nevertheless, he was obliged to abandon her. Who of us has not passed over in this purgatory without meeting some intelligent foreigner who swore that never again would he pay such a penalty for visiting England, and never would he counsel man or woman of his acquaintance to undergo the miseries and humiliation of this miserable passage across the Channel?

In truth, this great international communication between Europe and England is a degradation to all who endure it—a disgrace to three great railway companies—a blot on the administration of a great Emperor; and when we think ourselves the most practical nation in the world we are really perpetuating a great arterial system of communication which is barbarous and thoroughly unpractical.

It is well, therefore, to consider, in this meeting of naval architects and marine engineers, whether this state of international communication arises from any impossibility or impracticability standing in the way of expeditious, comfortable, and economical means of railway transport over the sea, or whether the causes are moral, financial, or intellectual incapacity in those who have the duty and responsibility of providing this public highway.

First, therefore, I may state that it is not the fault of engineers and naval architects that the public does not now enjoy the advantage of a railway across the sea. More than three years ago, an association of Englishmen was formed to carry railway trains across the Channel, between Calais and Dover. Of this association Mr. Fowler was the civil engineer, and I was the naval architect. All the measures which a private association of individuals could take for giving to our nation and other nations a civilised communication, were taken. Neither pains nor time were spared, and large sums of money were spent in making every preparation for giving the public this benefit. Unluckily we had to deal with an apathetic public, and with railway companies already in possession of the ground, with rival interests and disordered finances. The same bad political economy which has abandoned the public works of England to private speculation, rendered it impossible for this work to be then achieved, except through the co-operation of railways in a state of war and dilapidation. But the technical work had been thoroughly done. The harbours on both sides had been surveyed, and the working plans completed by Mr. Fowler; the designs of the ships to carry the railway trains across the sea had been completed by myself; and there, on the table, is the model on which they were to be built. The Act of Parliament was applied for, the money for all the expenses was found, and it was not the fault of engineer and naval architect that the thing was not then begun, and now done; there were no engineering difficulties not then solved.

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I am now to have the pleasure of bringing before you not the proposed plan for bridging the sea between Calais and Dover, but a similar undertaking which has been executed, and which is now in successful operation across a sea on a smaller scale. The Channel between Dover and Calais is 20 miles, and the Sea of Boden, or Lake of Constance, is at most 10 to 12 miles broad. There is the same difficulty of shallow water and narrow harbour entrance as at Calais, but extreme low water is rather shallower, and the harbour entrance narrower than at Calais. Of course there is no Atlantic wave, and no ocean ground swells, and therefore no low long swelling waves, and consequently never in the worst storm the great motion of our seas. But there is to an even greater extent than in the Channel, the sharp short breaking wave, which is both more dangerous and inconvenient than the long low swell; there is the terrific hurricane that sweeps down from the Alps, and which is probably not inferior in strength to a heavy Atlantic gale; and there are quite as many days in the year when no steamer can venture across the Sea of Boden, as when no steamer can cross the Channel. I think, therefore, the Sea of Boden is a fair scale on which to test a plan for conveying trains across the sea. Take it as half the distance, with waves half the size, wind half the strength, harbour entrances half the width, and a steamer half the length, and it will probably be considered as fair an experiment as can be tried.

The peculiar circumstances of this case are such as to present many difficulties, which need not be presented either at Dover or Calais. At Dover there is plenty of water; at Calais there are means of getting as much water as can be wanted, and an Emperor who has cut his way through the Isthmus of Suez can easily dredge a little sand out of the entrance to Calais; but on both sides of the Sea of Boden the water is shallow, while in the middle it is deeper than the Channel.

The entrances to the harbours in this lake have less than 100 feet of clear width, and one of them is so narrow inside as to be only two ships' lengths across. The ports, therefore, present greater difficulties than Dover and Calais; but there are no tides; that is to say, no daily rise and fall of the water; nevertheless, there are periods of rise and fall of 10 feet, or, again, about half the ordinary ranges between Calais and Dover.

The Sea of Boden, or Boden-See, or Lake of Constance, is an inland fresh water lake, 60 miles long and 10 to 12 miles wide. It separates Switzerland from Austria, Bavaria, Würtemberg, and North Germany, all of which have railway communication with Switzerland, and through Switzerland with central and southern France, which is cut off short, and stops abruptly on the shores of this lake, and the natural barrier formed by the lake is prolonged right down into Italy by the impassable Alps. The railway trains which last year fed France from the cornfields of Hungary, carried a continual stream of grain across Switzerland into France; but on the edge of this lake all this traffic was

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stopped—all the grain that might have passed right through in a wagon from Pesth to Lyons had to be unladen from one set of wagons at Lindau, in Bavaria, or Friedrichshafen, in Würtemberg, shipped into steamers or barges, unshipped on the other side, and re-laden into a new set of wagons. The cost and delay of this system, the accumulation of empty or laden wagons on both sides, the army of men for moving the sacks from ship to land, and from land to wagon, the accumulation of sacks on quays and under sheds, caused a hindrance, an inconvenience, and an expense, to avoid which many preferred to send their wares a long way round.

The impediment for passengers across the Boden-See was similar to that between Calais and Dover, although the accommodation for passengers on both sides presented those facilities which have only quite recently been introduced in our harbours, for on both sides of the lake the Swiss and German trains conveyed the passengers alongside the quay at which the steamers lie, and the passengers presented to the companies this advantage over goods that they were able to tranship themselves at their own inconvenience only.

Under these circumstances I was asked by M. Koller, an eminent Swiss engineer, and M. Schweizer, an able Swiss railway director, whether I would undertake to design a communication across the Sea of Boden by which railway trains and locomotive engines should pass continuously over the sea without interruption, and without change of carriage, so that a bale of goods or a passenger placed in a carriage in Switzerland or in Germany should pass right through from Vienna, Munich, Stuttgardt, Dresden, or Berlin to Zurich, Lucerne, Bâle, Geneva, Lyons, Marseilles, or Paris, or contrarywise to it. It was also a condition that I should, if possible, employ no steam engines, machinery, or power of any kind in the transfer except the ordinary locomotive engines employed in dragging the train; in short, I was asked to make an international communication across this sea as continuous and unbroken as between two stations on land.

This I have accomplished; and after frequent preliminary trials, it is now doing its daily work of railway communication. It takes over trains of fourteen to sixteen laden wagons at one time. The wagons weigh 70 to 80 tons, their contents 150 tons; they make the passage from harbour to harbour in from forty to fifty-five minutes, the difference being the index of the severity of the weather. The cost of the goods per ton per mile, varying with the quantity on board, is from three farthings to five farthings, including interest on capital, depreciations, and repairs. A locomotive engine on one side places the train on board; a locomotive engine on the other side takes it out. No peculiarity is required in the engine, nor in the mode of working it. No peculiarity is required in the wagons, carriages, their brakes, or their construction. The embarkation of a complete train occupies five minutes, its debarkation five minutes. All the practical

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difficulties which were anticipated and feared have disappeared with the actual facts, and that which was pronounced impossible, as so many new enterprises are, is now acknowledged to be "kinderspiel," or child's play. Indeed, now that it is done, the thing seems so obvious and so simple, that on returning home across the English Channel by the Straits of Dover, I was totally at a loss to conceive the reasons which could induce the intelligent English people and the great French nation to continue to endure the evils of their barbarous passage across the sea; while little Switzerland and little Würtemberg had provided for a less sea a convenient and unbroken highway.

I will now shortly describe the means by which this railway passage over Lake Constance is accomplished. The Swiss Railway which passes from Zurich to Romanshorn, on the Boden-See, is called the Nord-öst bahn. On the opposite side the German Railway terminates in Friedrichshafen, and is one of the royal Würtemberg lines constructed and worked by the State. Both harbours are so shallow that 6 feet is the maximum draught of water given for the ship. To carry the prescribed load of 14 to 16 carriages, two lines of railway are necessary on the ship throughout the length of 220 feet. For this purpose alone 22 feet of breadth are necessary, and as engines and boilers have to be placed on both sides of the railway, the ship has a breadth of nearly 40 feet without the paddle-wheels, which being each some 10 feet wide, the boat over all has a width of 60 feet.

The vessel itself, standing in its place in the harbour, appears to form a railway station; the land lines of railway being continued straight on throughout the length of the ship. The vessel has two decks, one below the railway train and the other above it. The upper deck forms a great part of the strength of the ship; double sides of iron plate connect the upper with the lower deck, and convert the whole body of the ship into an iron girder 25 feet deep at the centre, a construction which gives great strength to the body. The upper deck is the working deck of the vessel, from which the captain commands the engines, and where there are also two steering-wheels for the pilots. There is a rudder at each end so as to save the trouble of turning in the narrow harbours. Each paddle-wheel can be worked independently of the other, and each has two steam engines, so as to work readily and quickly, the four steam engines making up 200 horse-power to propel a ship of 1,600 tons. The upper deck does not extend quite to the ends of the boat, so that the passengers in carriages occupying the ends are enabled to enjoy the Alpine scenery without leaving their seats, and those who prefer a change find on the elevated deck a fine weather promenade.

The difficulty of uniting this ship to the railways on either side, so that the trains can run on and run off without the aid of any steam engines or machinery beyond their own locomotives, is overcome by means of a bridge suspended in the air by heavy weights capable of adjustment to the rise and fall of the water, and there is in the vessel a

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further provision to lower or raise her own extremities through a range of 5 or 6 feet, so as to diminish the inconveniences of the varying water level. There are, moreover, in the ship self-moving capstans, by which the engines can perform any exceptional manipulation that may be required either for the railway trains or the ship herself.

It is by the combination of all these contrivances that a navigation, which would otherwise have been impossible, has been rendered easy and certain. The two rudders and the two independent pairs of engines are an invaluable security against accidents, for one rudder being damaged, or its steering gear broken, an independent steering apparatus is ready for immediate use. In case of accident to either engine, or either paddle-wheel, the other wheel with its pair of engines is ready without a moment's delay to continue the voyage, and this experience has already been obtained, and the ship has performed a trip in less than an hour with one wheel and its engines; 15° of the rudder were found sufficient to steer a straight course, leaving an available steerage of 30° each way to direct the ship, and her captain experienced no difficulty in entering the harbour and placing the ship.

There is another result of the arrangement of engines adopted in this case, which has proved of the highest practical value. Each wheel has a pair of oscillating engines, similar to those of the Great Eastern. I designed the paddle-wheel engines of the Great Eastern, so as to be able, like these, to work each paddle-wheel independently of the other; and the result has proved in this instance to be of great importance. When large vessels come into shallow water, they are well known to steer wild, and their rudders cease to control their movements; by the prompt action of the independent paddle-wheels, which can be made to revolve either in opposite directions, or in the same direction, one fast or one slow, or one altogether stopped, there is no evolution performable by a rudder, which cannot be more quickly and handily done by the wheels alone; and this paddle-wheel steerage in shallow water, and in the entrances of harbours, has this great advantage, that it can be performed without way on the ship, or with as little speed as you choose.

For this particular case steerage by wheels has been found of greater value, and I dwell on it, because there are some difficulties in the way of its successful execution. The engines must be contrived, as those of the Great Eastern were, for prompt reversal; a code of signals must be contrived so that at the same moment the captain can give different or contrary orders to the engineers of opposite engines; not only so, but the code of orders, to be successful, must give more precise instructions to the engineer than are commonly given. The contrivance of this code and its use require superior intelligence in the captain and in the engineers; but the result has been found to be well worth the pains. The captain has a conning-platform in the centre of the upper deck,

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and thence a speaking tube to each engine-room; each engine-room has also an index which shews the engineer of one what the other is doing. The captain has also two indices on deck which shew him what each engine is doing, and so the captain and his two engineers are always at one, and thus a mistake is no sooner made than seen and remedied.

With a proper code of signals and the arrangement I have described, an intelligent sailor will readily see that he can do everything he wants; he can reverse the course of his ship in four, three, or two minutes, according as he uses both engines—one standing, or one reversed. When at rest, he can revolve on a pivot without moving; and when he wishes to run on a circular arc, he has only to order the right number of revolutions to be made with the outer wheel, and a smaller number to be made with the inner wheel, and the curve is described as accurately on the water as with a pair of compasses on a sheet of paper. To steer straight without a rudder is performed by each engineer watching the index of revolutions of the other engine, which is close to the handle, governing his own, and with only an occasional hint from the captain. After a little experience, this becomes quite easy.

As to the manœuvring of the trains and placing them on the ship, the arrangements are so simple that all difficulty has disappeared; and whereas it was supposed that sufficient experience might only be gained after serious accidents, the experience has been gained and the daily work proceeds without accident. No locomotive engine—not even an empty waggon—has been sent into the sea—events confidently expected. Carriages intended to cross the sea are left at the siding which leads to the ship. The locomotive engine which does the work of the station goes behind this train and pushes it on to the ship, one half on one side, and the other half by a second line on to the other side. The common brakes of the train and of the engine suffice for all the manipulation of the train, and there are special means in the ship herself to prevent the trains at sea from fetching way. In practice, the locomotive engines do not cross with the trains, for the Germans prefer their engines and the Swiss theirs. Only carriages and wagons go right through, and instead of 30 tons of locomotive, 10 tons of carriage and 20 tons of goods more profitably occupy its place.

I trust this verbal description, together with the official plans from which the ship was built, will give a sufficient idea of the manner in which the crossing the Straits of Dover may be safely undertaken and successfully executed; some of the difficulties are greater, and some are less. There is deep water at Dover, and Calais can be easily deepened. The boats must be twice as long, and can be made twice as fast. Suspended bridges can easily be thrown from the land to the ship as I have done; but with the changes necessary to the greater and continued variations of the tidal waters. In these

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larger and faster ships there can be room, comfort, and ventilation; and, if built with the proper kind of stability, sea-sickness will nearly disappear. The comfort of taking your bed carriage in London, and not having to leave it till you awaken in Paris, need not be enforced; and the economy and expedition which must arise from sending goods right through to their destination without change of carriage or wagon is thoroughly appreciated by all merchants and shippers. That the trade of Europe with England would enormously increase there can be no doubt; and the mails of India would reach Brindisi or Marseilles in the same carriages in which they would be stowed by the Post Office officials of St. Martin's-le-Grand. The question as it stands is, therefore, whether patient Englishmen will remain quietly content that the communication of their railway traffic between England and all Europe should continue in its present condition of barbarism.

In conclusion, I must say that it is not me the English people have to thank for having made this experiment for them, to shew them the practical way of continuing railway traffic over a wide sea on a large scale. I have already said that the problem was proposed to me by M. Schweizer and M. Koller, and not by me to them. The plan was first practically taken up by the President Escher and the Direction of the Nord-öst bahn, a railway managed and made by the Swiss, completed and set to work on less than its estimated capital, and in consequence of the wisdom, economy, and purity of its management, now paying its shareholders a steady 8 per cent. The proposal on their representation was willingly accepted by the Government of the small Kingdom of Würtemberg, which has conferred on its people, by economical State management, a complete network of railways, at very small cost. These two bodies undertook to carry through this improved communication for their mutual benefit, and its management and government is now incorporated with that of the railways. Having previously built an iron ship, which has for twenty years done satisfactory duty, on the same lake, I was asked to prepare the plans of a ship which should fulfil all the conditions of speed, safety, and manageability which the circumstances required; and also of the works on land necessary to communicate with the ship. These plans of the ship, when prepared, were sent for public tender to several of the best firms in England, Scotland, France, Germany, and Switzerland; and it was intimated to them that if they chose to send in a design of any ship better, safer, or more economical on a plan of their own, such a plan should have a preference over my own. The result was the acceptance of a tender by Messrs. Escher, Wyss, and Co., of Zurich—a firm which, in the third generation, enjoys a high reputation for having covered the Lakes of Switzerland with excellent steam ships. They ordered the iron for the ship from the Creusot Iron Works in France; the pumps from Berlin; the capstans, anchors, and cables from England;

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and their performance of the contract has been accepted as satisfactory. The works on the land at Romanshorn were executed under the direction of M. Seits, the resident engineer of the Nord-öst bahn, and those at Friedrichshafen, under the direction of Chief Engineers and Architects, Brockman, Binden, and Grund.

DISCUSSION.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): Having heard Mr. Scott Russell's lucid account of his railway, would any Gentleman wish to ask him any questions upon the subject? Perhaps, Mr. Siemens will say something.

Mr. CHARLES W. SIEMENS: I am not a naval man, though I occasionally take a swim on the seas when laying submarine cables.

The CHAIRMAN: It is an inland question, not naval.

Mr. SIEMENS: I have been very much pleased with the lucid description which Mr. Scott Russell has given us of the solution of a problem which seems to be involved in a good many practical difficulties; and all of which seem to have been overcome with that determination not to be beaten at any point, which after all is the true spirit of engineering. I hope to see between Dover and Calais a similar arrangement very soon adopted, before we are asked to spend money in making tunnels, or in building bridges across the Straits. I do not know that I have anything to say in illustration of the problem which has been put before us. The only question I would ask is, why locomotive engines should go across at all? It appears to me that it would be sufficient to put carriages on the ship, and apply some mechanical power for leading them on to the ship and for landing them. No doubt, Mr. Scott Russell has good reasons for making the locomotive engine itself cross the sea. I should like to hear what those reasons are.

Mr. C. W. MERRIFIELD, F.R.S.: I should like to ask Mr. Russell two questions of mere detail. One is, what is the total displacement of the vessel at her load draught? The other is, what are her total dead weights,—so as, by the difference, to get at the quantity of cargo, including the weight of the train, carried at one journey.

Mr. JOHN SCOTT RUSSELL, F.R.S.: 1,000 tons is the total displacement; 240 tons is the moving weight. Of that 240 tons, 50 tons are useless weight; the remainder is paying weight. The 50 tons are the carriages. Allow me to say, because this is a most important point, that the price of conveying goods upon this sea railway is, according to the weight of the train which happens to go, eight centimes, or eight-tenths of a penny, to twelve centimes, or twelve-tenths of a penny, per ton per mile. Therefore, you see, it is a very moderate railway train; and if you apply that rate to a ton of passengers you would find it extremely small. The other question was, why I took over the locomotive engine. The answer is, that I was ordered to do so. A great many locomotive engines do pass over. There are great manufactories of locomotive engines, and the owners thought that if the carriages went, surely a little

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more trouble on my part would enable the locomotive engines to go as well. It involved a little more trouble; because, being limited to weight, I had to put more strength under the rails than I should have done, and I had to shift the weight a little. But I may say, the reason why no machinery is used of a separate nature is, first, because it would cost money; secondly, at the two stations and harbours on both sides, there generally are locomotive engines manœuvring there; and it would be much more convenient simply to call one of those engines, than to have a separate engine to come and put the train on board, or to take it out. The thing is done, the engine goes away to her ordinary work, and there is no expense, no outlay of capital required. I thought it of great consequence not to make a separate engine; I should have wanted an engineman to look after it; I should probably have wanted a boiler, and so I should have increased the establishment; whereas I have not increased the establishment one jot, except to this extent, that two policemen have to come and crane down the bridge when it is required to be shifted. As to locomotive engines crossing with the train, I entirely agree with Mr. Siemens. But the one kingdom will have its locomotive engines, and the other kingdom will have its locomotive engines; probably they are jealous enough of each other to say, the German that he does not see why Swiss locomotives should be coming on to his railway, and the Swiss that he does not see why German locomotives should come on his railway. I believe, practically, the locomotives might stay in their respective countries, and the weight of the locomotive, instead of being uselessly carried across, might have as a substitute two wagons filled with paying cargo.

Captain JASPER H. SELWYN, R.N.: Will you allow me to ask a naval question, with reference to the comparison with Dover, whether the fact that, occasionally, no vessel can approach the shore at Dover, and then has to go round to some of the other ports, has entered into the calculation; and whether provision has been made in such a contingency to discharge the cargo, independently of facilities on shore?

Mr. SCOTT RUSSELL: I am happy to say that the same event occurs exactly in my case. In my case there are days when a prudent captain will not go out. I hope there will also be found prudent captains between Dover and Calais, who would be wise enough, if they found they were not likely to get into harbour on the other side, to stay at home for better weather.

Mr. W. M. FENNING: As a sea-sick passenger I take a great deal of interest in the success of this scheme. I have very often thought that something of the same kind might be done. I have asked the captains of the different boats at Dover to tell me their ideas about it, and I have invariably been met with two objections. One is, as to the depth of water at Calais; the other is, that with a vessel of such dimensions as Mr. Russell has mentioned and driven at a high rate of speed, in a place so crowded as the Channel the risk of collision would be very great; for there can be no question that, if it is to pay, and be a railway communication, great pace would be necessary. I have gone over at night, and chatted with the captains, and they say, "How could we stop a vessel of the size and speed you talk of, when even with vessels of moderate proportions we frequently find it difficult to avoid collisions?" Again, I would ask, how would vessels approach both sides of Dover Pier?—because sometimes they can only approach one side and sometimes the other. Also, is it possible to construct a vessel so as not to roll?—because my recollections of rolling are peculiarly vivid.

Mr. SCOTT RUSSELL: As to the pace, we have an excellent ferry between England and Ireland. The pace there is 18 miles an hour; I hope that will please the Dover captain. As to the rolling of

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vessels, I hope no vessel I shall ever build will fail to roll, because if it were to fail to roll when the sea rolled, it would become a rock, and it has not strength enough to do the function of a rock. Therefore, I hope that all vessels that I have anything to do with will roll. All that I can hope to do is this, so to construct the vessels that they shall roll with moderation. But I am afraid some very heavy storm must come when some delicate stomach must be slightly affected, under the most favourable circumstances. The next point is the captain's difficulties. His difficulties are quite right. They were the difficulties of my captain. My captain refused to command my ship. Every captain said the ship was impossible. I am ashamed to have to confess that I had to navigate the ship myself the first time; and having done so, it was *Kinderspiel!* Now the secret of all that is in one word, the power of steering without the rudder. If you cannot steer without a rudder; you must go a pace; you must go a steerage pace; you must go so as to have steerage way in all circumstances; and you must rush into your harbour, in order to get in somehow or other. I have done that a thousand times with most excellent captains. I have seen this, that in order to keep steerage way, we have been obliged to go into narrow harbours at a pace which sometimes has shipwrecked the ship on the pier, which always incurs very great danger, and which always requires the highest courage a captain can possess. Therefore, I entirely agree with the captains, that they could not handle an ordinary ship in these harbours in extraordinary circumstances. But this was our point; by the engine alone we can steer the ship without any way whatever. And what is the rule I have made for these ships? I will tell you. The rule for these ships now is this, that they never go into harbour at a pace which will give steerage way; that they stop and reverse just before they come to the entrance, and stop and reverse so that they are at a dead halt when they get the paddle-wheels between the two piers. I need not explain to you that at a dead halt there can be no collision. In this dead halt the captain calls down, "Left, forward three!" He gives no order to the right, and "Left, forward three!" turns the ship round along the quay. That is how it is done. Now, all these things are impossibilities to the captain who has not seen them. But once a captain has seen them, it is that German word "*Kinderspiel!*"

Mr. FENNING: The other point is, whether it is possible to construct a vessel of that size with a sufficiently small draught of water to get into Calais harbour.

Mr. SCOTT RUSSELL: Calais has the same draught at its worst that my harbour at Frederichshafen has; the two are just the same. But I agree with you that the harbour at Calais is too shallow. I only hope that a great emperor of a great country, who has sent out thousands of horse-power of dredging machinery to dredge the Isthmus of Suez, might be persuaded to put a little dredging machine in front of Calais harbour, and deepen the entrance a few feet. I hope Calais harbour will be improved. It very much wants improvement. It is one of the parts of the passage which I am afraid is a disgrace to one side or the other, I will not say which. In regard to one point I have not mentioned, we got into a nice mess once. Some little thing about one of the engines gave way before our captain had acquired experience or confidence; and we were left to go our way into a harbour where as I told you we could have no steerage way, and where we had only one engine. The captain was in despair. We had the following result. We ordered the other engine to go on. We took one rudder, and we found that with 15 degrees of the rudder—the rudder being able to take three times 15—and with one engine we went perfectly straight, and nearly as fast as two engines. Then, we had got the remainder of the engine to play upon 15 degrees each way, and the ship never went more comfortably or more quickly into harbour than she did that time when we went in with one of our engines broken.

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A VISITOR: Has the gangway a single rail, or will it have double rails?

Mr. SCOTT RUSSELL: A double rail.

The VISITOR: Does the vessel run square?

Mr. SCOTT RUSSELL: Perfectly square. She is a continuation of a railway station. When you are on land, looking on board, you do not see a ship.

Captain DE HORSEY, R.N.: I think Mr. Russell is a little too sanguine in thinking his passengers will not be sick; and also a little too sanguine in expecting to get 18 knots out of a vessel that is fitted for carrying a train. I daresay Mr. Russell knows a great deal better than I do that the Americans, who are very clever at these things, have had railway ferries running for years and years across the lakes of Canada, at Buffalo, Sarnia, and Detroit. These are running day and night. They are remarkable vessels, and carry trains; but they do not run more than ten knots. I protest, however, against the idea that any vessel can be built to cross the Channel in which passengers will not be sick in bad weather.

Mr. SCOTT RUSSELL: I am glad to say that that difficulty in the construction of the ship is met by one circumstance,—length. With the ship that I have now got, I could not do more than 12 knots an hour with her present power. But between Dover and Calais our ships must be 400 feet long; and there they were always intended to be so. They have as fine lines on the outside as the boats that run between Holyhead and Dublin; and they would carry a train notwithstanding. Here is a model on the table. It is not exactly that of the vessel which I designed to go between Dover and Calais, but it is very nearly so. Captain de Horsey, who I know is a sailor, will see from the fineness of its lines that they are lines calculated for 20 miles an hour. From the length of the vessel you may judge that she is a vessel meant for speed. Then you will see that the model of this vessel is carried a great deal further than I carry it here, where I have carried the deck. This is not the train deck; this is the deck underneath which is the train deck. Anybody who will take interest enough to look at it will see the arrangements of the under deck. There is the railway train in the centre; and on both sides are railway platforms, railway offices, and railway refreshment rooms, sleeping rooms and cabins. All that is got in as fine a ship as I can conceive. Here we have the upper deck, corresponding to the upper deck in my ship; and on the top of that we have charming cabins and a platform. Now, I do not say that some of our dearly-beloved passengers will not get a little sick now and then. All I can do like a good doctor is to try to give them as good an antidote as I know how to produce. I can go no further than this; and I think I will undertake this, from what I have seen of the beautiful boats between Holyhead and Dublin. Between Holyhead and Dublin, where the sea is much worse, owing to the excellence of the boats, the excellence of the air, and the excellence of the accommodation, there is not one passenger sick for ten that are sick between Dover and Calais. I merely say that the passage might be much alleviated; that it might be much accelerated; and that the inconvenience of changing carriages, especially in the night, and of walking about wet piers and wet decks, might be entirely removed.

The CHAIRMAN: I am sure we have all been very much amused as well as instructed by Mr. Russell's lecture, and the pleasant duty remains to me to ask you to thank him for the treat he has given to us.

The Meeting was then adjourned to the following day.

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ON LONG AND SHORT IRON-CLADS.*

By E. J. Reed, Esq., C.B., Chief Constructor of the Navy, Vice-President.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; the Right Hon. Sir John S. Pakington, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

In the design of our earliest iron-clad frigate, the *Warrior*, dimensions and proportions were adopted far exceeding those of the longest and finest wood ships which preceded her. The *Minotaur* class, designed in consequence of the desire to obtain complete protection, have even a greater proportion of length to breadth than the *Warrior*, and are considerably larger; but in them, as in the *Warrior*, economy of steam-power was one of the great features of the design. Our more recent ships have less extreme proportions and dimensions, and in their design economy of steam-power did not occupy, by any means, so prominent a place. Before proceeding to discuss the relative merits of long and short iron-clads, however, it may be well to give the lengths and proportions of a few of our principal iron-clads, and to compare them with those of our longest and finest wood ships.

Ships.	Length.		Breadth.		Proportion.
	Ft.	in.	Ft.	in.	
Unarmoured :—					
Longest three-deck line-of-battle ships ...	260	0	61	0	4·3
„ two-deck „ „	254	9	55	4	4·6
„ frigates	300	0	52	0	5·8
Armoured :—					
Warrior	380	0	58	4	6·5
Minotaur	400	0	59	4¾	6·7
Bellerophon	300	0	56	1	5·3
Hercules	325	0	59	0	5·5
Monarch } turret ships {	330	0	57	6	5·7
Captain } {	320	0	53	0	6·0

* Received 19th March, 1869.

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From these figures it will be seen that, in consequence of the armour plating of about 213 feet amidships, the *Warrior* was made 80 feet longer than the longest wood ships; and that complete protection in the *Minotaur* was thought to require an additional length of 20 feet, making 400 feet in all. There can be no question that the objects kept in view by the designers of these ships—the carrying of a large weight of armour on a hull so formed as to be driven at a high speed with a proportionally moderate engine-power—were very satisfactorily attained. The question arises, however, whether the objects on which the designs were based were themselves wise. My own opinion on the subject is well known, and may be briefly summed up in the statement that it is unwise to make an iron-clad very long, large, costly, and unhandy, in order to effect a comparatively small saving in the engine-power. It has been my duty to carry into practice principles of design totally opposed to those exemplified in the *Warrior* and *Minotaur*.

The new method of design received its first illustration in the *Bellerophon*, and in that vessel has undergone a series of trials, the results of which are of a most satisfactory character. It has also been applied to the *Lord Clyde* and *Lord Warden*, which are 280 feet long and 59 feet broad, the proportion of length to breadth being about $4\frac{3}{4}$ to 1, and in these short, bluff, and completely protected ships, has proved quite as successful as in the *Bellerophon*. All our recent iron-clads have similar moderate proportions, and the ship last tried, the *Hercules*, has afforded another, and most striking, illustration of the benefit resulting from this course. Our experience with long and short iron-clads, and the official reports of trials of speed and turning-power, may, I think, be fairly stated as follows: That the short ships may be driven as fast as the long ships by a moderate addition to their engine-power; that in turning-power and general handiness under steam and sail, the short ships are much superior, and that the great reduction in the prime cost of short ships much more than makes amends for the addition to the steam-power. In thickness of armour, and in character of armament, I need hardly say that the more recent ships are superior to the long ships first built.

Without discussing further the actual trials of long and short iron-clads, I shall proceed to consider the subject from a more theoretical point of view. Scientific writers upon the forms and resistances of ships have generally recommended the adoption of forms of least resistance; and have taken no account whatever of the effect which the weight of the material in the hull should have upon the form of a ship. The most cursory glance will, however, be sufficient to shew that this generalisation cannot include the designs of all ships. Take, for example, the vastly different conditions to be fulfilled in a merchant ship and in an iron-clad war ship. The former is designed to carry cargo economically, and the weight of hull forms a comparatively small fraction of the total

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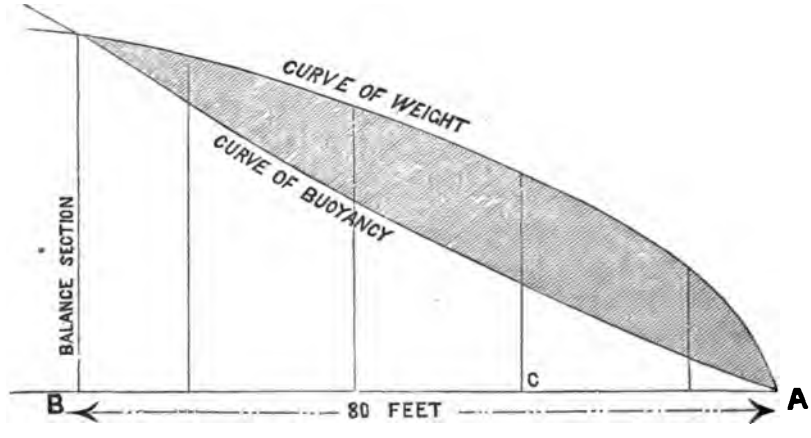
displacement; while the latter is in reality a floating fortress, constructed with a view to efficiency in powers of offence and defence, and carrying great quantities of armour, the weight of which depends upon the form and proportions of the hull. The merchant ship may, with advantage, be made long and fine, since the requisite carrying power can be secured as well by means of great length as of great beam; and the proportion of speed to engine-power is thus increased. In the iron-clad, however, any addition to the length leads to a corresponding increase in the area of the surface to be armoured, and in the unproductive weight to be carried; while a reduction in the length leads to a considerable decrease in that area, and in the total weight of armour.

The impossibility of correctly prescribing any general form of ship, in disregard of the armour, will exhibit itself even more strikingly if we consider independently one end of a ship, say the bow or entrance. To fix our ideas we will take the case of the *Minotaur*, for which ship it has been found by actual calculation that in still water the weight of the first 80 feet of the bow exceeds its displacement by about 420 tons.* This excess of weight must clearly be floated by the central part of the ship where the buoyancy exceeds the weight; and the length of this part being 250 feet while its mean breadth is about 56 feet, its immersion must be increased by about 13 inches, in consequence of the unsupported weight forward. This additional immersion increases the area of the midship section which has to be propelled through the water by from 60 to 65 square feet. Now, let us imagine this bow to be so shortened and shaped—on the one hand increasing its buoyancy, and on the other diminishing its weight—as to produce an equilibrium between its total weight and buoyancy. No doubt by making it bluffer we shall increase its resistance to motion through the water, but we shall at the same time lighten the burden upon the central part of the ship, and reduce the total area of



* A graphical representation of the distribution of weight and buoyancy over this portion of the *Minotaur* is given in the accompanying diagram; in which the lengths of the ordinates of the curves of weight and buoyancy at any station, such as C, represent, on a certain scale, the weight and buoyancy of the part of the ship to which that station corresponds. At the balance section, where the weight equals the buoyancy, the two curves cross, and the area of the space enclosed by the curves between this point of intersection and the bow represents the excess of weight (420 tons) over buoyancy on the first 80 feet.

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the midship section to be driven, as well as the total weight. It is easy to see that by this means we may succeed in getting the same speed with a given power, as would have been obtained by employing the longer and finer, but much heavier bow. This is the essence of the principle which I have laid down, and carried out in practice.

In the design of all merchant steam-ships, the conditions to be fulfilled are so similar, and the proportions of weight of hull, equipment, and cargo to displacement are so nearly the same, that we should expect to find a similarity of form in the greater number of these vessels. Nor is our expectation disappointed; for although differences do exist, they are not usually of a very striking character; and this fact makes the adoption of the ordinary "constants" for steam performance a very fair standard of excellence for merchant ships. For armoured war-ships the case is very different; and these constants are by no means to be taken as standards of merit, as I shall shew almost immediately.

The constants here referred to are, I need hardly say, estimated from the two formulæ,

$$(1) \qquad \text{Constant} = \frac{(\text{Speed})^3 \times \text{Midship Section Immersed}}{\text{Indicated horse-power}}.$$

$$(2) \qquad \text{Constant} = \frac{(\text{Speed})^3 \times (\text{Displacement})^{\frac{2}{3}}}{\text{Indicated horse-power}}.$$

These formulæ are always used in calculating the results of the trials of ships of the navy. In them it is assumed (1) that, within certain limits, the resistance to a ship's motion varies as the square of the velocity, and that, therefore, the propelling power must vary as the cube of the velocity; (2) that the resistance also varies, *cæteris paribus*, as the area of immersed midship section in the first formula, and as the two-thirds power of the displacement in the second formula; (3) that the indicated horse-power bears a constant ratio to the useful work of the engine,—*i.e.*, to the power actually available for propulsion. These assumptions are not, of course, strictly accurate; but they are sufficiently so to render the constants of much service in comparing performances, and in determining the engine-power needed in a new design.

I may remark in passing, that the method of calculating the horse-power just referred to, is much more reliable than any methods based upon more theoretical investigations. Nor is this a matter of surprise, when it is remembered that the difficulties surrounding the subject of fluid resistance are very great, and that the amount of experimental knowledge possessed regarding it is very small. On the other hand, a glance through the elaborate table of trials printed by the Admiralty, enables one to select some ship, similar in form and proportions to the new design; and from the constants obtained by this ship, to calculate the horse-power required for the estimated speed, with a very fair amount of accuracy.

While recognising the value of the constants, however, I cannot entertain the

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opinion that they should form the sole standards by which all steam ships, armoured as well as unarmoured, should be judged. Such an opinion virtually amounts to a belief that the chief aim of the naval architect ought to be the lowering of the proportions borne by the indicated horse-power to the speed attained, to the midship section immersed, and to the displacement. As far as *form* alone is concerned, this view is no doubt correct; but obviously, if carried out in its entirety, it would lead to the construction of ships that would carry no weights except those of the propelling apparatus. This is, of course, an extreme case, and it may be thought unfair to argue from it the folly of the system as a whole. But if economy of steam-power is the chief desideratum in ship design, the case imagined is also the fullest development of the principle; and if we once admit other considerations besides form—such as cargo-carrying power, first cost, and handiness—the failure of the constants as criteria is tacitly acknowledged.

There can be no doubt that in merchant ships increased proportions and fineness of form have led, and do lead, to increased carrying power, and to economy of steam-power; and that in such cases the constants of performance have higher values. The lightness of the hull would, in my opinion, tend to produce these results, and I have previously stated that for merchant ships—and it is true also for unarmoured war ships—the constants are very fair standards of excellence. But with iron-clad ships, if a similar mode of comparison were followed, we should in many instances be comparing vessels of which the armour was of extremely different degrees of efficiency, and should, at the same time, wholly exclude this important fact from our consideration.

For example, if the *Warrior* and *Bellerophon* were compared, we should have the former with comparatively thin armour plating, extending over a little more than half the length; and the latter protected with thicker armour throughout the length at the water-line, besides having armoured central and bow batteries. It would obviously be most delusive in comparing these ships to waive all consideration of these facts, and to take constants of performance as the sole criteria. In fact, such a course would be equivalent to requiring that the proportion of weight of hull (including armour) to the displacement, should be considerably greater in the shorter than in the longer ship. At the same time, the other most important points connected with first cost, character and weight of armament, and handiness, would be entirely neglected.

In short, constants of performance can only be of use in comparing the merits of two iron-clads when there is similarity, or at least equality, of construction, armour, and armament; and when this condition is satisfied, the conclusions based upon the values of the constants must be supplemented by considerations of cost and handiness. The merits of iron-clad ships do not consist in carrying a large proportion of weights to

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engine-power, or having a high speed in proportion to that power; but rather in possessing great powers of offence and defence, being comparatively short, cheap, and handy, and steaming at a high speed, not in the most economical way possible, but by means of a moderate increase in power, on account of the moderate proportions adopted in order to decrease the weight and cost, and to increase the handiness. It must be obvious that if a ship 300 feet long, plated all over with given armour, carrying a given armament, and costing say £300,000, steams at a given speed with a given power, it would be a mere waste of money and a sacrifice of handiness to build her 400 feet long, at a cost say of £380,000, for no other object than that of driving the great weight at the same speed, with about the same power; in other words, for the mere purpose of raising the constants.

It may, perhaps, be objected to this statement that the trials of actual ships do not shew that a ship 300 feet long can be driven at the same speed, with about the same power as a ship 400 feet long, when the armour is equally efficient in the two ships. Now, I need hardly say, that in dealing with speed-trials great care is required in order to ensure a fair comparison of the performances of any two ships. So many causes of difference exist, that until it is known that they are either inactive, or else acting similarly, in the ships compared, the comparison is of little worth. The quality of the coal, the character of the stoking, the condition of the engines, and the state of the bottom, as well as the force of the wind and condition of the sea, are the chief causes of error in such comparisons; and the reports on the performances of our iron-clads prove that greater varieties of speed are due to these, so to speak, secondary causes, than are shown to exist when the ships are first tried on the measured mile. This is a most important fact, requiring to be borne in mind when the policy of our naval construction is being discussed; for the present I only refer to it as connected with the speeds actually attained on trial.

With these prefatory remarks, I desire to introduce to your notice the results of a series of trials which took place in the Spring of 1868, and which were conducted in such a manner as to eliminate, as far as possible, the effects of these sources of error; care being taken to ensure equally good coal and stoking, the bottoms being cleaned almost immediately before the trials took place, and the engines, as the trials showed, being in excellent condition. The ships tried were the *Minotaur*, *Bellerophon*, and *Warrior;* but for the present, I shall confine attention to the two first-named vessels, as their performances will throw some light on the point now under discussion. It has been found by actual calculation that the weights per square foot of the protecting material—armour and backing—in these ships, when uniformly distributed over the surface of the side from the lower edge of armour up to the upper deck, are very nearly identical; so

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that it may fairly be assumed that if the *Bellerophon* were completely protected, she would have quite as strong armour as the *Minotaur*, the excess in thickness of the skin-plating in the *Bellerophon* over that in the *Minotaur* being put into armour. Hence, it follows that these ships may be taken as representatives of the 300 feet and 400 feet ships previously referred to.

Before being tried by a six hours' run at sea, the ships were put over the measured mile in Stokes' Bay, where the *Minotaur* attained a speed of 14·411 knots with an indicated power of 6,702 horse-power, and the *Bellerophon* realised 13·874 knots with an indicated power of 6,002 horse-power. With a greater power by 700 horse-power, therefore, the *Minotaur* beat the *Bellerophon* by about half a knot. This trial does not help us much in our investigation; but the six hours' trials are of exactly the right character for our purpose, since on them the indicated horse-powers were, as nearly as possible, identical. On this trial, when the *Minotaur* had only been out of dock nine days, she made 14·165 knots with 6,193 horse-power; and on a similar trial the *Bellerophon*, which had been twenty-one days out of dock, made 14·053 knots with 6,199 horse-power. As the Controller of the Navy remarked in his report on these trials "The *Bellerophon* had the "disadvantage of having been twice as long in the water as the other two ships, and at this "time of the year (the Spring) the growth of weeds is particularly rapid;" so that allowing for the greater foulness of her bottom, it may be fairly stated that her speed was nearly identical with that of the *Minotaur*, when the engines of the two ships developed equal power. I do not for a moment intend it to be supposed that a single trial of each of these ships, however carefully conducted, is sufficient to establish the general principle that 300 feet and 400 feet ships of the character previously described always should steam at the same speed, with about the same power. But, on the other hand, it is right to state that on this, the only occasion when such ships have been tried under similar conditions, they did perform in accordance with that principle; and this fact shews the want of force in the objections supposed to be based on the results of steam trials.

I may add in this connection that, to again quote from the Controller's Report, "These experiments prove that with good coal and good stoking, there is but little "difference between the results of the trial at the measured mile and one lasting for six "hours on the open sea, all the circumstances being alike;" and the fairness of the measured mile trials, as tests of steaming capability, is thus strongly established. It is also worth notice that the discussion of the merits of our long and short iron-clads, as developed in their various trials at sea, has often run into error, on account of the speeds attained having alone been considered, and the horse-power developed at the time of trial having been neglected. Such a course is obviously incorrect, as the connection between horse-power and speed is indissoluble; and it has been truly said that complaints of fallings off

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in speed, which were really due to smallness of horse-power, amount to complaints that the hull did not drag the engines along at a greater rate than that at which they were working. The fact is that all the long iron-clads have engines of the old type, which had been gradually improved upon, until, apart from the great consumption of fuel, it had been made to approach perfection; and not only was the development of the guaranteed power ensured, but in many cases that power was considerably exceeded. The recent short iron-clads, on the other hand, have the new type of engines with surface condensers, superheaters, and other novel arrangements, which, like all newly-introduced mechanical contrivances, are liable to occasional failures that could hardly have been foreseen, and can be easily remedied; but that, for the time, cause very mistaken notions of their true character. As experience is gained in the construction and working of these improved engines, they, like the older type, will no doubt be perfected; but, at present, their performance is not nearly of so certain a character as that of the more wasteful type which preceded them. It has happened, in consequence of this fact, that on some occasions the power developed in, and the speed obtained by, our short ships at sea, have fallen considerably below the corresponding results on the measured mile trials; and in published reports of these so-called failures the low speeds have been given without any mention being made of the want of engine-power. I have already referred to the unfairness of this course, and need only add that the results of the trials of all the short ships may be summed up in the statement, that when the engine-power has reached the amount guaranteed, the estimated speed has been attained; but that when the power has fallen off, the speed also has necessarily declined. It is not the function of a ship to propel her engines, but to be propelled by them, at a speed exactly proportioned to the power exerted; and this is a complete answer to a multitude of complaints respecting the performances of short ships.

As far as our experience goes, then, I am warranted in making the assertion that in armoured ships as the extent and thickness of the armour to be carried are increased, the proportion of length to breadth should be diminished, and the fulness of the water-lines increased; and that the shorter, fuller ship can be propelled at as great a speed as the longer finer ship with about the same, or only a little greater, horse-power. The constants of performance will undoubtedly be lower in the shorter ship; but they are only hypothetical standards of merit, and the benefits in point of first cost, handiness, and maintenance, resulting from moderate proportions, are tangible facts, far outweighing in importance the small economy of steam-power resulting from the adoption of greater proportions and fineness of form.

One other point requires attention when we are discussing the propriety of building very long iron-clads—the fact that in such ships the proportion of frictional resistance to

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direct head resistance becomes considerably increased. It appears probable, even, that if very extreme proportions were adopted, the advantages resulting from the reduction in head resistance, would be more than counterbalanced by the increase in frictional resistance. To illustrate this statement, I will suppose a fully armoured ship to be lengthened amidships, and made fine at the extremities with a view to increased speed in proportion to engine-power. In such case a great weight of armour would be added; the strength of the hull proper would require to be increased; and the immersed surface would be made so much greater as to render it questionable whether the saving in horse-power, or the increase of speed, if any, would be at all commensurate with the increased cost, or make amends for decreased handiness. Adding to this the considerations that a greater area of immersed surface means a greater area subject to fouling, and that one of the chief causes of falling off in speed of a sea-going iron-built ship is foulness of bottom, we may, I think, fairly conclude that this is a feature of the question which ought not to be overlooked.

That this is so will, perhaps, appear more clearly if I refer to the results of one or two trials of actual ships. Before doing so, I would observe that the advocates of long iron-clads have at various times urged the importance of increasing the proportions borne by the displacement and the midship section to the indicated power, and have declared our recent iron-clads to be wanting in these, which they consider the "chief elements of naval architecture." Having so fully stated my own opinion on this matter in a previous part of this Paper, I need hardly say that in using, as I shall do, these measures of efficiency, I only wish to make a comparison between two long ships in a manner of which those who favour long iron-clads must approve, and that I by no means agree to this method of comparing the merits of armoured ships.

The trials to which I refer, are those which took place in the Spring of last year, in which the *Warrior*, *Minotaur*, and *Bellerophon* were engaged. Taking the six hours' trials at sea of the two long ships, it is found that the proportion of horse-power to displacement in the *Minotaur* was 603 to 1,000, and in the *Warrior* 553 to 1,000, while the proportion of horse-power to midship-section immersed was 468 to 100 in the *Minotaur*, and 404 to 100 in the *Warrior*. In other words, the horse-power is *less* per ton of displacement, and per square foot of midship-section in the *Warrior* than in the *Minotaur*, although the latter is the longer ship and has the greater proportion of length to breadth. It is proper to state that the *Minotaur* steamed faster than the *Warrior*, so that her proportion of horse-power was on that account somewhat greater than that of the *Warrior*; but in order that the proportionate expenditure of power might be the same in the two ships, the *Minotaur's* indicated power would have to be diminished by more than 500 horse-power, which is doubtless a greater diminution than would be

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necessary if the *Minotaur* were driven at the *Warrior's* speed. Here then we have a result which follows from the adoption of a standard of merit brought forward by the advocates of long iron-clads, but which goes against the theory that increased length and proportions tend to increased economy of steam-power. I shall be glad to see this seeming contradiction explained, if it be possible; for my own part I am inclined to think that these facts are confirmatory of the opinion previously expressed, that in very long ships the increase of frictional resistance is so considerable as to become, at least, as important as the decrease in direct head resistance. At the same time I do not wish to appear to base a general theory on one or two trials; and there can be little doubt that limits do exist at which the increase of length ceases to be beneficial, whether these limits have as yet been reached or not.

In the course of last year special attention was drawn to the relations which should subsist between the form and dimensions of iron-clad ships and the weight of material in the hull, in a Paper read by me before the Royal Society, and since published in their *Transactions*. By the phrase "weight of material" I mean the weight of hull per unit of surface, say per square foot, and when the armour is included this is very different in different ships, varying with the extent and thickness of the armour. The methods and arguments of the Paper are, in reality, applicable to both completely and partially-armoured ships, including in the latter class ships like the *Warrior* without any protection at the extremities, and the very much more efficient ships with armour belts, and central, bow, or stern batteries. In order to make a fair comparison, however, between ships having different arrangements and thicknesses of armour and backing, I have thought it proper to distribute the total weight of protecting material over the whole length of the broadside in each case; thus, in fact, turning all ships into equivalent, but completely protected ships, for the purpose of comparison. By this means a fair idea can be obtained of the relative defensive powers of the ships considered, before any steps are taken to compare their performance under steam. To afford a general view of the methods employed and the results arrived at, I have given the following abstract, which is a reprint of that sent to the Royal Society:

Abstract of Paper sent to the Royal Society, "On the Relation of Form and Dimensions to Weight of Material in the Construction of Iron-clad Ships."

The object of the Paper is to shew that the proportion of length to breadth in a ship, and the form of her water-lines, should be made in a very great degree dependent upon the weight of the material of which her hull is to be constructed—that an armour-plated ship, for example should be made of very different proportions and form from those of a ship without armour, and that as the extent and thickness of the armour to

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be carried by a ship are increased, the proportion of length to breadth should be diminished, and the water-lines increased in fulness.

It is highly desirable that this subject should receive the attention of men of science, not only because it bears most directly upon both the cost and the efficiency of future iron-clad fleets, but also because it opens up a theoretical question, which has hitherto, the author believes, received absolutely no consideration from scientific writers upon the forms and resistances of ships, *viz.*, the manner in which the weight of the material composing the hull should influence the form. Prior to the design of the *Bellerophon*, the forms of ships were determined in complete disregard of this consideration, and even the most recent works upon the subject incite the naval architect to aim always at approaching the form of least resistance. The investigations given in the Paper shew, however, that the adoption of a form of least resistance, or of small comparative resistance, may, in fact, lead to a lavish outlay upon our ships, and to a great sacrifice of efficiency; while, on the other hand, the adoption of a form of greater resistance would contribute in certain classes of ships to great economy and to superior efficiency.

In order to indicate clearly, but approximately only, the purpose in view, the author first considers the hypothetical cases of a long and a shorter ship, both of which are prismatic in a vertical sense. The length of the long ship is seven times its breadth, and its horizontal sections consist of two triangles set base to base. The length of the short ship is five times its breadth, the middle portion being parallel for two-fifths of the length, and the ends being wedge-shaped. It is assumed also, that at a speed of 14 knots, the long ship will give a constant of 600, and the short ship a constant of 500 in the Admiralty formula:—

$$\frac{\text{Speed}^3 \times \text{Mid. Section}}{\text{Indicated horse-power}}.$$

The draught of water is in each case 25 feet, and the total depth 50 feet.

It is taken for granted, that the form of the long ship has been found satisfactory for a ship of such scantlings that we may consider her built of iron of an uniform thickness of 6 inches, the top and bottom being weightless.

Now let it be required to design a ship of equal speed, draught of water, and depth, but of such increased scantlings (whether of hull proper or of armour) that the weight shall be equivalent to an uniform thickness of 12 inches of iron, the top and bottom being weightless as before. First, the new ship has the proportions of the long ship given to her, and secondly, those of the shorter ship. In each case the engines are supposed to develope seven times their nominal horse-power, and to weigh (with boilers, water, &c.), 1 ton per nominal horse-power. The coal supply in each case equals the

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weight of the engines, so that both ships will steam the same distance at the same speed. But as the equipment of the smaller ship will be less weighty than that of the larger ship, we will require the larger ship to carry 2,000 tons, and the smaller 1,500 tons additional weight.

Assuming the breadth extreme in each case to be the unknown quantity, we can, from the Admiralty formula given above, deduce an expression for the indicated horse-power; thence under the assumed conditions the weights of engines and coals can be found; and these being added to the weights of hull (calculated on the assumption that the sides are of 12-inch iron) and to the weights carried, give an expression for the total displacement, in tons, of each ship. Another expression is found for this displacement by finding the weight of water displaced. The two expressions are equated, and a quadratic equation is formed, from which the breadth extreme is determined, and from it all the other values can be found.

The accompanying Table shews the results obtained by this method for the two classes of ships:

	Long Ship.	Shorter Ship.
Length, extreme	581 feet	342 feet
Breadth	83 „	68½ „
Nominal horse-power	1,350 H.P.	1,337 H. P.
Indicated „	9,450 „	9,359 „
Weight of hull	12,570 tons	7,576 tons
„ engines	1,350 „	1,337 „
„ coals	1,350 „	1,337 „
Weight carried	2,000 „	1,500 „
Total displacement	17,270 „	11,750 „

It will, therefore, be seen that by adopting the proportions and form of the shorter ship, a ship of the required scantlings and speed will be obtained, on a length of 342 feet, and a breadth of 68½ feet; whereas if the proportions of the long ship are adopted, the ship, although of the same scantlings and speed only, will require to be 581 feet long, and 83 feet broad, the steam-power in both cases being as nearly as possible the same.

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Considerations of this character, worked out more fully, led the designer of the *Bellerophon* to depart so considerably from the form and proportions of the *Minotaur*.

The next part of the investigation is based upon the official reports of the measured mile trials of the *Minotaur* and *Bellerophon*, when fully rigged, and upon calculations made from the drawings of those ships. It is assumed that a prismatic vessel having the same mean draught as each of these ships, and having the same form and dimensions as the mean horizontal section—which equals the mean displacement in cubic feet, divided by the mean draught of water—will give the same constant as the ship herself at the assumed speed of 14 knots, which, as nearly as possible, equals the speed obtained by both *Minotaur* and the *Bellerophon* on the measured mile. For each ship the weight of the armour and backing is supposed to be uniformly distributed over vertical prismatic sides of the dimensions of the armoured sides, and the weight of hull is similarly distributed over vertical prismatic sides of the dimensions below water of the mean horizontal section, and above water of the armoured side. The actual weights carried by the ships are thus transferred to what may be termed representative prismatic vessels, having the same constants of performance as the ships. The detailed calculations in the Paper shew that the weight per square foot of the material in the hulls of the two ships, when distributed over the sides of the representative prismatic vessels, is very nearly the same for both, and the same holds with respect to the weight per square foot of armour and backing. The *Minotaur* is rather heavier in both respects, but for the reasons given in the Paper, the means of the values found for the two ships are taken, and are found to be:

Weight per square foot of hull = ·152 ton.
„ armour and backing = ·11 „

The questions next considered are these: presuming it to be necessary to build another ship which shall also steam 14 knots, carry the same proportionate supply of coal to engine-power, and proportionate quantities of stores, but shall have her armour and backing of double the weight of armour and backing of the *Bellerophon* and *Minotaur;* then, 1st, what will be the size, engine-power, and cost of the new ship of the *Minotaur* type, and having the same mean draught and depth of armour; and, 2nd, what will be the size, engine-power, &c., if built on the *Bellerophon* type, and having her mean draught and depth of armour? this condition implying of course that the same constants of performance as before will be realised in each case. On account of the great disproportion in size between the two types of ships, it is obvious that the smaller one will require much less weight of equipment. It is assumed, therefore, that the additional weights of the smaller ship (exclusive of engines, boilers and coals) amount to 700 tons, and those of the larger ship to 1,000 tons. The developed

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power of the engines, proportionate supply of coal, and the weight of engines, &c., are taken exactly the same as in the hypothetical case first given.

By proceeding with the investigation for each case in a way similar to that sketched for the hypothetical ships, only treating the breadth extreme of the mean horizontal sections of the new ships as the unknown, the following results are obtained. The new ship of the *Minotaur* type which fulfils the required conditions will be nearly 490 feet long, 72½ feet breadth extreme, and have a total displacement of 14,253 tons, while the new ship of the *Bellerophon* type is 380 feet long, 71 feet breadth extreme, and has a total displacement of 10,950 tons. It thus becomes obvious that a correction is needed in the weight per square foot of hull in the new ship of the *Minotaur* type, as her length has been so greatly increased; it is considered that an increase of at least 10 per cent. is required, and this is the allowance made. On the other hand, the new ship of the *Bellerophon* type is still shorter than the *Minotaur* herself, and the displacement is not much greater than the actual displacement of the *Minotaur*, so that no correction is needed in her weight per square foot of hull. When the correction has been made for the new ship of the *Minotaur* type, the final results in round numbers are as follows for the two classes of ships:—

	New Ship of *Minotaur* type.	New Ship of *Bellerophon* type.
Length	510 feet	380 feet
Breadth	75 „	71 „
Tonnage	13,770 tons	8,620 tons
Nominal horse-power	1,080 H.P.	1,080 H.P.
Indicated „	7,560 „	7,560 „
Weight of hull	7,100 tons	4,460 tons
„ armour and backing ...	5,190 „	3,630 „
„ engines and coals ...	2,160 „	2,160 „
„ stores carried	1,000 „	700 „
Displacement	15,450 tons.	10,950 tons.

Taking the cost per ton at £55 (which is the average cost per ton of tonnage for the hulls of armour-clad ships), the saving made by adopting the new ship of the

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Bellerophon type would amount to £283,250, or considerably more than a quarter of a million sterling.

It must also be considered that the ship of the *Bellerophon* type would cost less for maintenance and repair, and be much handier in action.

The last investigation in the Paper, is purely theoretical, and consists of a determination of the dimensions which would be required in two ships, of which the horizontal sections are curves of sines, and which are prismatic vertically, if they were built with the same weight per square foot of hull (say ·1 ton) as the *Bellerophon*, but carried twice the weight of armour per square foot (say $\frac{6}{28}$ ton). In these cases the bottom is taken to have weight as well as the sides, the speed for both is 14 knots, the draught of water is 25 feet, and the depth of the armoured side 24 feet. One of the ships is seven times her breadth in length, and the other is five times. Professor Rankine's Rule for the calculation of horse-power and speed is employed, and the same conditions of engines, &c., are assumed, as have been indicated previously. The larger ship carries 1,350 tons additional weight, and the smaller 900 tons.

The results obtained for these ships are as follows, when expressed in round numbers:

	Larger Ship.	Smaller Ship.
Length	585 feet	425 feet
Breadth	84 „	85 „
Nominal horse-power	1,267 H.P.	980 H.P.
Indicated „	8,890 „	6,860 „
Weight of hull	7,586 tons	5,540 tons
„ armour and backing ...	6,124 „	4,470 „
„ engines and coals	2,540 „	1,960 „
Weight carried	1,350 „	900 „
Displacement	17,600 tons.	12,870 tons.

These results are very different in detail from those obtained in the cases based on the actual trials of the *Bellerophon* and *Minotaur*, but not greater than might have been anticipated from the adoption of such a different form of ship, and mode of calculating

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resistance. The 2,000 horse-power, which is needed by the larger ship above the power required by the smaller ship, is principally due to the difference between the immersed surfaces of the two ships, and is spent in overcoming friction. The immersed midship-sections, it will be remarked, only differ by a very small amount.

This last investigation serves to shew that the theoretical best form of ship being taken, and the most recent rule being applied in the calculations, the speed of 14 knots can be obtained in the short type of ship at a surprisingly less cost and size than the long type requires, and this result agrees with that of the preceding investigation based on actual trials.

I will now refer briefly to another aspect in the case of long *versus* short iron-clads. Supposing two ships to be constructed, having the same central, bow, and stern batteries, and the same height of port above water; the same depth and thickness of armour in the water-line belts; the same proportion of weight of hull to total surface; and the same equipment and armament; with engines of the same type, and with weights of coal which would enable them to proceed equal distances at the same speed, would the advantage, on the whole, rest with the ship which had the form and proportions of one of our long iron-clads, say the *Minotaur*, or with the ship having more moderate proportions, say those of the *Hercules?*

It will be obvious that this is a different case from those considered in the Royal Society Paper; and one in which the disadvantage of the long ship, as compared with the short ship, is not so great as in those cases. In the wholly armoured ship in passing from a short to a long ship, we increase the armour very largely; while in the case now about to be discussed, we propose to lengthen the belted portion only, and therefore get the benefit of length with a less burden of armour. Still we shall see, that, even in this case, the short ship is to be preferred to the long.

I have taken the *Hercules* as the representative short iron-clad, and have used the known quantities representing her weights of hull, of equipment and armament; and of engines, boilers, and coals at the time of her trial; and of armour and backing on batteries and belt, in order to determine the corresponding quantities in the new design for a ship having the same form and proportions, below water, as the *Minotaur;* but in other respects, fulfilling the same conditions as the *Hercules*, in the manner explained above. I have also taken the indicated horse-power developed in, and he full speed realized by, the *Hercules* on her load-draught trial, in order to determine the proportion of indicated to nominal horse-power in the engines which would drive the new ship at the same speed, thus ensuring that the new ship shall have engines of an identical character

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with those of the *Hercules*. In determining the coal supply of the new ship, I have considered it proper to provide such a weight as would enable her to proceed at the half-boiler speed attained by the *Hercules*, as far as the *Hercules* could steam at that speed. This is obviously just to the long ship, as the half-power speed is the maximum which would be employed in all cruising services when under steam.

As the result of careful calculations made in accordance with the above-stated conditions, I am enabled to give the following dimensions and particulars of the new ship; and in order to compare them with the corresponding features in the *Hercules* at the time of trial, I have arranged the subjoined Table:

	New Ship.	*Hercules.*
Length between perpendiculars	385 feet	325 feet
Breadth, extreme	57 ,, 2 inches	59 ,,
Tonnage B.O.M.	5,936 tons	5,226 tons
Nominal horse-power	925 H.P.	1,200 H. P.
Indicated ,, ...	6,585 ,,	8,529 ,,
Weight of hull	4,574 tons	4,022 tons
,, armour and backing, in belt ...	1,518 ,,	1,292 ,,
,, armour and backing, on batteries	398 ,,	398 ,,
,, engines, boilers, and coals ...	1,460 ,,	1,826 ,,
,, equipment and armament ...	1,138 ,,	1,138 ,,
Displacement...	9,088 ,,	8,676 ,,

From these figures it will be seen that the new ship would be 60 feet longer, and 1 foot 10 inches narrower than the *Hercules*, and that she could be driven at the same full speed by engines having a nominal power 275 horse-power less than the engines of the *Hercules*. Her tonnage, however, is 710 tons greater than that of the *Hercules*, and her construction would consequently cost considerably more, while her engines would cost less, and her expenditure of fuel not be so great as that of the *Hercules*. Hence, apart from the question of handiness, it becomes necessary in contrasting the merits of these ships to determine the difference of prime cost approximately. Taking £55 per ton of tonnage as the cost of the hull, which is a fair average for iron-clads, and taking £60 per nominal

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horse-power as the cost of the machinery, which is also a fair average, we obtain the following results:

	Tons. H.P.	£	£
Excess in the prime cost of the hull of the new ship over that of the *Hercules*	= 710	× 55 =	39,050
Decrease in the prime cost of the machinery of the new ship from that of the *Hercules*	= 275	× 60 =	16,500
Excess in the prime cost of the hull and engines of the new ship over that of the *Hercules*			= £22,550

This will, I think, be admitted to be a considerable saving, and one which can scarcely fail to shew the desirability of building ships of moderate proportions, even if we have to increase the engine power in order to obtain the very high speed.

There may, however, still be a suspicion in the minds of some advocates of long ships, that the additional cost of maintenance for the more powerful engines of the *Hercules*, would in a comparatively short time make up for the difference in the prime cost, although that difference is considerable. I shall attempt to shew what the difference of cost of maintenance may amount to, in order to clear up this point; but before doing so I must draw attention to the fact that the new ship, being more than 700 tons burden greater than the *Hercules*, will require an addition of at least fifty men to her crew, and that the cost of their maintenance will be considerable. Taking £70 as the average total cost per man per annum, this would involve an additional annual outlay on the large ship of £3,500. From calculations based upon the average consumption of coal in ships with the improved type of engine, it appears that the cost of fuel in the new ship, for a day's steaming (24 hours) at half-boiler power, would be less than that in the *Hercules* by a little over £15. Hence it follows that the saving of wages and provisions in the *Hercules* as compared with the new ship, would cover the difference in the cost of steaming at 12 knots for 229 days, of 24 hours each, in the year. I need hardly say that our iron-clad ships are not under steam for anything like that time in a year, and consequently the difference in cost of fuel for the two ships would be much more than counterbalanced by the smaller expenditure required on the crew of the *Hercules*.

Even if this necessary difference in the numbers of the crew were waived, it will be obvious from the facts just stated that the *interest*, at a low rate, on the difference of prime cost, would quite make up for the additional cost of fuel in the *Hercules*, supposing her to be in commission and on general service. This matter, in my opinion, is thus placed beyond question.

Having disposed of this objection, it is only fair that I should call attention to the facts that the *Hercules* being smaller, is sure to be less costly in repairs than the new ship would be; and that the fact that she is 60 feet shorter cannot fail to render her

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much handier. In several parts of this Paper, I have had occasion to refer to this latter feature of short iron-clads; and it may be thought that undue stress has been laid upon the point. A study of the reports of the admirals of the Channel squadron will, however, shew that experienced seamen also hold the opinion that handiness is one of the most important features of a ship of war. I need not quote from those reports in proof of this statement, but may add that the length of the *Achilles*, *Warrior*, and other of our long iron-clads has again and again been pronounced so great as to interfere with the manœuvring power, while the shorter ships—such as the *Bellerophon* and *Lord Warden*—have been warmly praised for their handiness. The *Hercules* has also been shown to possess exceptionally good manœuvring power.

On a review of the facts brought before the Institution in this Paper, it can, I think, be scarcely doubted that the policy of building armoured ships of moderate length and proportions is superior to that of adopting greater length and fineness of form. The change from the *Minotaur* to the *Bellerophon* was undoubtedly very great; but, I submit, that experience has shown it to be a proper one, and the construction and trials of other ships of nearly the same proportions have tended to confirm this view. In prime cost, handiness, and general efficiency short ships have been shown to be better than long ships. In economy of engine-power long ships may be, and in some cases undoubtedly are, superior to short ships; but since this economy is inconsiderable in proportion to the total saving, it may be fairly concluded that the shorter iron-clads are, on the whole, greatly to be preferred.

DISCUSSION.

Mr. JOHN SCOTT RUSSELL, F.R.S.: Perhaps I may be permitted to make some observations upon this matter, as the *Warrior* and *Warrior* class have been taken by Mr. Reed as the subject of comparison with his class. I think it is unjust to Mr. Reed himself, to compare his class with the *Warrior* class, because the *Warrior* class was invented for other purposes, and with other views, than those for which Mr. Reed afterwards wisely invented the smaller class, *Bellerophon*. I think it is also unjust to both, to compare them as if they had been meant for similar purposes. I can venture, perhaps, to speak with some authority upon that subject, for it is, I think, understood that the *Warrior* class was invented and created jointly between the Controller's Department and myself. We have agreed to say that we are joint and equal owners in the credit and discredit which may attach to the *Warrior* class—I mean, as technical men. With regard to the Admiralty who decided upon producing the *Warrior* class, I think a great deal of credit is due to them in quite another way, namely, for having resolved resolutely to make, as far as they could, the best possible class of ship which the state of our knowledge and invention could then give to the world; and they did a very able thing, as it appeared to me at the time it was done, for they said, "We will not take these designs of our own people, and we will not take Mr. Scott Russell's "design until we have gone out into the technical world and ascertained whether anybody cannot give us

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"something better." And it was only after all the eminent engineers and shipbuilders who had been applied to, had sent in their designs, that a design compounded of mine and the Department's was accepted and executed. I may venture, under these circumstances, to say what were the purposes and intentions of the *Warrior*. There is one great element in the construction of the *Warrior*, which was in fact the principle upon which she was constructed, and which has not been mentioned by Mr. Reed; therefore he does injustice to his own ship, and also does injustice to the *Warrior*, by the comparison which he has made. I am always sorry to be compelled to enter into details when the time is limited; but I am afraid I cannot make myself intelligible, or this discussion useful, without doing so to some extent. It seems to be assumed that the proportion of the *Warrior* is that which was originally intended to be her proportion, and that what has been ultimately arrived at is in accordance with the original intention. It seems to be assumed that the length of 380 feet was arrived at for the purpose of getting a long bow, a fine entrance, and small resistance to steam-power. No such idea ever entered into the heads of the constructors. It is quite true that the *Warrior* has a fine bow, and small resistance to steam-power; but it is not true that that fine bow is the cause of her length, or has anything to do with her length. That fine bow forms only a portion of the ship—in my design, a very marked portion of the ship. But there is a great parallel midship body, which great parallel midship body gives to the *Warrior* her great length, and it is not attributable to her bow. Mr. Reed very properly says that he has not given us the *Warrior's* bow, but the *Minotaur's* bow, which I must say appears to me to afford the greatest possible contrast to the bow of the *Warrior*. The *Warrior's* bow has no such curve, or weight overhanging or overweighting it. It was an abuse of the beautiful lines of the *Warrior* to load them with armour, and enable Mr. Reed to produce such an abominable exhibition as we have upon the diagrams before us. I say it is abominable, and I feel that there are many here who will think as I do. The man who put that armour upon that ship, had no conception why the bow was designed. Whose work it was, and who loaded the *Minotaur's* bow with that top weight I do not know—I did not, and I do not think the Surveyor of the Navy did. Although I am at this moment as strong an advocate as ever I was in my life of having a fine bow, so as to raise very little resistance to the water, and especially to make way through a head sea in heavy gales, and although I deem that to be of enormous importance, yet I am not at all contrary to Mr. Reed's view of cutting off so much of that long bow as gives him something better in exchange for it. Therefore, when Mr. Reed builds a short ship, and says, "I build a short ship in order that I may get power of manœuvring," I entirely approve of his motive. I say, I would cut off the point of a long ship, and give you a short ship with a full bow if you compelled me to carry armour upon her, and also compelled me, as the first condition of my ship to be able to manœuvre her in a small space. I, who love the wave bow because it is my own child, say that I will sacrifice it to what you require; therefore I entirely approve of what Mr. Reed does in that respect. But I will go back to the *Warrior*. The *Warrior* had a fine bow—for the purpose, Mr. Reed has said, of consuming little coal, making great head-way, and especially, making a good passage in bad weather, to all of which things the fine bow is essential. But her length is not due to the fine bow. Her length is due to a great quality which the practical men in the Admiralty of that day told me I must enforce. I was put in personal communication with sailors, which I insisted upon, for the purpose of making me understand what the qualities of the ship were that they required. The first sailor I was put in communication with in that respect was Admiral Milne, and the second sailor I was put in communication with was Admiral Dundas. Those gentlemen gave me leave to do what I think a most

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important thing—they gave me leave to make a middle battery, or partial battery, to the ship, and they gave me leave not to overburden her ends with armour, and so make her a heavy ship. This was the basis of the partial battery and the central battery, and the central battery I am happy to say Mr. Reed adopts, and to the central battery he adheres in opposition to many enemies. And we are justified, for the French produce partial batteries in their vessels. A partial battery means the ends not loaded with armour. But there was a question, at the commencement of the *Warrior*, whether we should or should not carry the armour on the lower body of the ship to the ends of the ship. It was Admiral Dundas who encouraged me not to do that. He had great doubts of our carrying the central battery with good qualities to the ship, and he said, "Do not let us load the ends of the ship with weight; but let us begin "with this, our first one, and gradually add on the armour afterwards, if we find that it can be done "without harm." Therefore, the *Warrior* was the right number one, and the *Hercules* was the right number two, for the *Hercules* was an attempt to carry on that armour in a smaller quantity to the two ends, and so to make progress. But instead of making progress, they knocked down the whole of the experiment altogether, for some one came and took that class of ship, lengthened it, and loaded it from end to end with armour. That was a folly—an insanity; and I am quite satisfied that Mr. Reed should oppose that with his great eloquence and energy. Nothing could have been more absurd or improper. I say, as to the length of the *Warrior*, it was produced, not by her sharp ends, but by the necessity of a long middle body, to do two things—the one, to carry the central battery, and the other, which Mr. Reed has forgotten, or did not know—I daresay he did not know it—with regard to her capacity for carrying coals. In the original design of the *Warrior*, the sailors insisted that long endurance at sea should be the first condition of her construction, that she should carry coals for 6,000 miles, and that she should endure a voyage to the Indies and China if necessary. That was the cause of her length. The requisite capacity to carry 2,500 tons of fuel was the cause of her long middle body, and that was the purpose for which she was constructed. Allow me to say that there is no comparison—no just comparison—whatever, to be made between the *Warrior* and the *Warrior* class originally designed, for long enduring sea ships, whether for the siege of certain ports which shall be nameless, whether for getting quickly at an enemy a good way off, who shall be nameless, whether for remaining a long time outside, whether for catching it when you least expect it, or whether for the hundred and one other purposes which were gone over at that time, and which it would be imprudent in me to go further into now. These were the purposes for which the *Warrior* was designed, and I say that endurance in a ship can only be attained by length of middle body—mark, I am not saying a word about the bow. To this you add—what? Such a bow as may be necessary, and such a bow as may be convenient. Again, to this you add—what? Such a stern as will answer for the steerage, and form a proper stern for the ship. But the middle body is the capacity, the fighting part, and the useful part of the ship. That is class No. 1. Then class No. 2, the *Bellerophon* class, is designed with totally different views. Mr. Reed knows that I have always admired the *Bellerophon*. According to my judgment of the *Bellerophon*, she is a perfect ship, but of another sort. The *Bellerophon* is intended to be a quick, handy and short ship in difficult and intricate waters. She is meant to meet another class of enemy than the *Warrior*. She is meant for a class of enemy nearer home. She is intended for other purposes, and is good for other purposes than those for which the *Warrior* and the *Warrior* class is intended. The following, in my judgment, are the elements of a ship:—Endurance is got solely by a long middle body to hold coals—it is only that vulgar function of holding the coals; and it is the great advantage of a

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long middle body, that it holds the coals without expending them. The middle body of a ship may be lengthened with hardly any increase to the resistance offered by the ship. There is a slight increase, by reason of the addition of skin, but that increase, as compared with the facility for carrying coal, is extremely small. Speed is quite another thing to endurance, and has nothing whatever to do with the length of the ship. I wish that to be as broadly and emphatically put as I can. Length, and proportion of length to breadth, which is the old foolish antiquated doctrine, has nothing to do with the speed of the ship. I can tell you that as a matter of certainty, for I was once foolish enough to build a ship fourteen times as long as she was broad, for the purpose of getting the greatest amount of speed I could, by proportion of length to breadth; and I can assure you, from the result of that experiment, that the idea of proportion of length to breadth having anything to do with speed is perfectly fallacious and ridiculous. A given length of bow will give you a given speed without the least reference to the breadth of the ship. Then comes the question, what has breadth got to do? Breadth has got a great deal to do. Again, I agree with my friend Mr. Reed, as I am always happy in doing. If you want a tolerably short and handy ship, do not make a long one, but make a broad one, and the broad one will give you power to carry armour. But there must be the requisite power to drive the ship. It will require a big engine, it will use up the coals very fast, and it will not have a large store of coals for a long voyage, in proportion to its consumption. But Mr. Reed need not be ashamed of that—on the contrary, Mr. Reed may say to his masters in the Admiralty, "If you want a ship of a certain length, mind, you can only carry so many "tons of coal to so much horse-power, and you cannot carry more," and Mr. Reed cannot make you carry more. Therefore, Mr. Reed need not be at all ashamed of it, because it is a thing which is beyond his control, and arises as a necessary consequence, from the necessity of the case. Then with regard to handiness, I am entirely with Mr. Reed, and say, "If handiness is to be one of the conditions, have a "short ship—cut off the beautiful wave bow, and make her handy." That a ship should be able to reverse her course in two minutes is, for a fighting ship of that class, a first-rate quality, and if I had to build such a ship to-morrow, I should cut off the nose of my own child, and make the wave bow as short as Mr. Reed has done for the purpose of accomplishing that object.

Mr. Charles Lamport: I desire to make a few remarks with regard to the Paper which has been read by Mr. Reed. If it is intended by him to lay down the rule of proportion of length to breadth as a general one, all I can say is, that his views, as he has enunciated them, are in opposition to all the knowledge and experience gathered amongst nautical men and shipbuilders. If, on the other hand, he puts upon one side the general principle, and says that he takes his stand upon specific reasons, then I think we are bound to look only to those reasons, and discuss the proposition from the point of view which he has placed before us. He says, "I am willing to sacrifice a great deal to attain certain specific qualities." Those qualities are, principally, economy in construction, and handiness in manœuvring. Now as regards economy in construction, Mr. Reed has omitted to state the relative cost of the two ships which he has been comparing, ton per ton. We all know, as practical men, that the proper way of calculating is by taking the capacity of a ship as well as the outlay, and a very fair criterion in calculating the relative expense is obtained by taking the cost per ton. Of course, if Mr. Reed builds a ship 300 feet long, he can construct her for less money than would have to be expended in the construction of a vessel 400 feet long. There can be no doubt about that, and no one would question it for a moment; but when we come to the question of capacity, and when we come to the question of performance, then I say the comparison

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cannot be entertained. I put it to Mr. Reed whether, if he were to take his own *Bellerophon*, cut her in the centre, and put 20 feet more in, he would not derive great benefit from the exchange. Then another thing with regard to the cost is this. The *Minotaur* will cost a good deal more money to build, but the difference in the cost of working the two ships is also great, and I would ask him to take that difference and see whether it will not pay a very good per centage on the extra original cost. Supposing the *Minotaur*, which is 400 feet long, cost £100,000 more than the *Bellerophon;* and supposing the *Minotaur*, by doing a certain amount of work in a given time, saves in the working £5,000 or £10,000 a year, in economy of fuel, or otherwise, I would ask Mr. Reed to set the one off against the other, and see if there is not an ample return for the extra cost.

Mr. REED: As Mr. Lamport seems to be under some misapprehension, I may be permitted to state that she requires the same fuel, and a large number of extra men.

Mr. LAMPORT: I am glad to be corrected when I am in error. We were told, if I mistake not, that the *Bellerophon*, to do the work of the *Minotaur*, would require 2,000 more indicated horse-power to drive her at a given speed. That 2,000 horse-power will cost money, and my argument is this:—That that money, taken at interest, will more than pay a fair return on the extra prime cost of the *Minotaur*. We then come to the next point, namely, that of handiness. And here, I must express my sincere regret that Mr. Scott Russell sat down without saying more than he did upon the subject; for this reason:—I heard him last night state that he had designed a ship, and worked her to come out of harbour almost in a circle: manœuvring her with only the engines; the rudders being locked at both ends and not moved at all. Of course it cannot be for a moment denied that handiness is a quality necessary in all sea-going ships, and especially in all fighting ships; but I confess I do think it is a great pity to commit this country to such a type as Mr. Reed has done in the case of the *Bellerophon*, in the face of a prospective change as is on the eve of accomplishment, namely, the general introduction of the twin or double screw. Then there remains the question as to the cost of repairs. Mr. Reed has very properly said that a short ship will require less in the way of repairs than a long one. Looking at it in the abstract, that might be so; but if the result of having that shorter form of ship is to subject her at sea to greater strain on her structure, the long ship being easier, then, I say, the chances are that the repairs bill will be turned the other way; and the balance will be changed by the fact that the less amount of material is subject to the greater strain. Mr. Reed has stated, as another element of expense, that in a larger ship you would require a larger crew. I ask, why? If the engine-power is the same, and the stoker's work the same, why rig her differently? It is not essential to rig the longer ship in any different way from the manner in which you would rig the shorter one. As the chairman stated yesterday, we are going to have ships built without any masts at all; therefore, in order to effect economy, we might put in the longer ship the masts and spars of the shorter ship, of the *Bellerophon* class, and send her out to sea with the same number of men. I confess it seems to me that that item of expenditure may be put simply on one side. I have now said all that I have to say with regard to the Paper which has been read; but I cannot sit down without using one minute of my ten to express my gratification, and I am sure that of all present, at the manner in which Mr. Reed has placed his views before us. I think it a misfortune to this Institution,—I am almost inclined to think it a misfortune to the country, that Mr. Reed has such forcible eloquence, such clearness of statement, and the power of making the worse appear the better cause. I sit here, and ask myself, after Mr. Reed has ornamented his statements in the manner he is so capable of doing, whether or not I am right with regard to that of which I before felt certain. I think it was Warren Hastings who said,

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after having heard Sheridan's or Burke's speech, "that if he had not possessed the consciousness that his "principles were pure, he should have believed himself to be one of the greatest criminals upon earth." We may with propriety say of Mr. Reed, what was said of our greatest orator—*non tetigit quod non ornavit*—He touches nothing that he does not ornament. But that may be ornamented which is not true; and I am afraid that Mr. Reed, with that earnestness which we know carries all clever men and men of genius, in a groove, almost to the extent of absurdity, has, in this instance, been ornamenting that which will not bear strict examination as a correct nautical theory upon which it would be safe to rely.

The PRESIDENT: I wish to say before this discussion proceeds further, that in consideration of the great interest of this Paper, and also in consideration of the eminence of the writer, I imagined, and I hope not wrongly, that I should be acting in accordance with the wishes of the Meeting, if I were somewhat indulgent towards Mr. Reed on the point of time. But although I have thought it right to adopt that course in this particular instance, I think you will agree with me that our rules, so long as they remain in force, should be adhered to as nearly as possible; and I trust that the unusual length of this Paper will not be drawn into a precedent, so as to justify any future deviation from our rules, so long as they exist. I wish it to be understood that I am not now desirous of shortening this discussion; on the contrary, as it is a most interesting one, I shall be glad to hear any further observations which may be made upon the subject; but it is my duty to tell you that if the discussion is to proceed further, I can only sanction it upon the understanding that such is the general wish of the Meeting. [The Meeting signified their assent by acclamation.]

The Right Hon. the EARL OF LAUDERDALE, K.C.B., Admiral: I will not detain the Meeting; but should like to mention one point which has not as yet been referred to. Mr. Reed has drawn two vessels by way of illustration, a long one and a short one. I beg to ask Mr. Reed whether it is his opinion that by his plan he can propel the short vessel with a speed equal to that of the long one, with an equal amount of head sea, both vessels having the same displacement and steam-power? It has not been stated whether the short ship and the long one have been tried in a sea-way. In smooth waters, very possibly a short ship may be made to go as fast as a long one; but, in a certain sea—a sea where a short vessel will take two "bobs," as we may call them, where a long one will only take one, I cannot believe that she can be propelled with the same speed as a long ship. Mr. Reed may possibly be able to give us some further information upon the subject. Again, there is one thing which I may mention with regard to the bow. A long bow will go through a heavy sea, and may be forced through it, whereas the bluff bow has not the same advantages, and cannot be forced through a heavy sea in the same manner, without drowning the vessel, or shaking her to pieces.

Captain JASPER H. SELWYN, R.N.: I wish to ask a question which can no doubt be readily answered. Does any additional displacement, such as there would be in the case of a flaring bow take place during the pitch? I think the weight mentioned was 80 tons.

Mr. REED: 420 tons, on a length of 80 feet.

Captain SELWYN: Then there is the weight of 420 tons put in motion, due to the pitch of the vessel, with nothing whatever to sustain it, unless there be such an increase of displacement as will compensate for it. It amounts to a jerk communicated to 420 tons, suddenly stopped, and brought back again. I think naval architects will see the reason pretty clearly why sailors have always said, "If you give "us sharp bows, give us flaring bows," because that will ease the pitch of the ship, by giving additional

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displacement during the pitch, and in the case of armour-plates and heavy water, will do away with the awful excess of weight that we see before us. I may draw attention to the fact that there are two ways of getting speed by means of a fine bow. One is the wedge system, which is at present advocated by most shipbuilders throughout Europe, and the other, the salient of the solid of least resistance, which is in use by most Oriental nations. Take, for instance, by way of illustration, the segment of the sphere, where you get the greatest containing body, and by prolonging it in the shape of a beak, a useful form may be obtained. Take the segment of an elongated bullet. All the qualities of supporting weight may be got in that way, and may perhaps be usefully got, without any such liability as we see here to overloaded bows. Some people have thought that under such circumstances no ship could go to windward. All I can say is, that the Chinese junks do, and very often beat our finest and fastest screw vessels. I think there is a great deal worth studying with reference to the solid of least resistance, elongated, and placed upon the water.

Mr. JOHN MAC FARLANE GRAY: In the formulæ referred to by Mr. Reed it is assumed, as he has stated, that the resistance varies, *cæteris paribus*, as the area of the immersed section in the first formula, and as the two-thirds power of the displacement in the second formula. They are, however, virtually both midship section formulæ. The linear dimensions of similar solids vary as the cube root of the solidity, and therefore $D^{\frac{1}{3}}$ bears a constant ratio to the area of the immersed midship section in hulls of similar form, whatever be their actual dimensions. The second formula has been originally constructed on this principle. But the length of immersed hull L is also proportional to $D^{\frac{1}{3}}$, and $\frac{D^{\frac{1}{3}}}{L}$ will be a constant ratio; we may therefore write $D^{\frac{1}{3}}$ in the numerator and L in the denominator of the second formula, without affecting its validity, as an expression for a constant for vessels of similar form. We have therefore:

$$C = \frac{S^3 \times D^{\frac{1}{3}} \times D^{\frac{1}{3}}}{H \times L}.$$

Performing the multiplication, we get:

$$C = \frac{S^3 \times D}{H \times L}.$$ *

This I have found to be a more valuable formula than either of the others, as it gives a co-efficient which is more nearly a constant. By placing *length* in the denominator it puts a value upon shortness, and

* *Examples of the Application of the Formula* $C = \frac{S^3 \times D}{H \times L}$, *referred to by Mr. Mac Farlane Gray.*

			Full Boiler Power.			Half Boiler Power.			Estimated Value of C for a Speed of 12 knots.
	L	D	H	S	C	H	S	C	
Warrior ...	380	8,852	5,469	14·356	12·602	2,867	12·174	14·660	14·872
Lord Clyde ...	280	7,626	6,065	13·842	11·910	3,153	11·736	13·919	13·619
Prince Consort ...	273	6,700	3,953	12·770	12·927	1,842	10·086	13·671	13·167
Himalaya ...	340·5	4,250	2,189	12·805	11·972	1,050	10·230	12·687	12·220
Bellerophon ...	300	6,372	5,956	14·237	10·252	3,119	12·103	12·073	12·176
Hercules	325	8,680	8,598	14·690	9·766	4,045	12·122	11·760	11·880
Pallas	225	3,661	3,581	13·058	10·116	1,906	11·078	11·605	10·714
Lord Warden ...	280	7,675	6,705	13·496	10·049	4,080	11·777	10·974	10·770
Black Prince ...	380	9,180	5,144	13·318	11·093	3,568	11·664	10·774	?
Helicon	220	943	1,610	14·500	8·134	878	12·480	9·509	9·890

Where L stands for length, D for displacement, S for speed, and H for indicated horse-power.

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becomes a fairer standard for comparing the performances of long and short ships. This co-efficient is so nearly alike in vessels of great length and in vessels of the short type, that it may be taken as a constant for the performance of all steamers under similar conditions. If so, it follows that in practice the horse-power for a given length varies simply as the displacement. The co-efficient varies from 8 to 12, and is generally about 10 in actual service. It also varies from 10 to 14, and is generally about 12 on trial trips for the engines working at their normal speed. If the engines are driven beyond that speed the co-efficient varies inversely as the speed of the ship. The highest co-efficients I have found are from the ocean steamers lately introduced by Alfred Holt, of Liverpool. They have single engines, high and low pressure cylinders, and a fly-wheel on the screw shaft. I cannot say to which of these peculiarities we should attribute the high co-efficient.

Mr. Scott Russell: Will you permit me to ask, how high?

Mr. Mac Farlane Gray: As high as 14 on the voyage. If we adopt 10 as a standard co-efficient, the formula gives this simple proportion. The displacement divided by the length and multiplied by 100 is the horse-power required for 10 knots at sea. Applying the formula to the vessels of our navy, it shews that the recent short ships are quite equal to some, at least, of the long ones. The trial trip of the *Warrior*, on half-boiler power, gives 14·66. This is an exceptionally high co-efficient, but it is nearly equalled by that of the *Lord Clyde*, a vessel 100 feet shorter. It gives 13·919; the difference is equal to only one-fifth of a knot upon 12 knots, for the speed varies as the cube root of the co-efficient. This amount of difference is within the limits of error of observation: as the *Warrior* gives the highest, so the *Black Prince* gives about the lowest; and between these two (vessels of equal length) lie the co-efficients of all the short armour-clads. If a vessel is lengthened, so that its displacement is increased in the same proportion that its length is increased, then by this formula the power required for the same speed would be the same as that required for the shorter ship. But such an increase of displacement is not at all an increase of accommodation. The object of the naval architect is to secure the maximum amount of available displacement, and a certain speed at the least expense. If the expense of building were altogether neglected, and only the economy of power for a given speed considered, then the limit to length would be attained, when any further increase would increase the ratio between the gross displacement and the available displacement, in the same proportion that the length was being increased. In merchant vessels, where the available displacement is the largest proportion of the total displacement, the maximum of length, with regard only to the economy of power, has never been reached; but the limit has always been determined by considerations of first cost. In ships of war, however, where the available displacement is the smaller proportion, this limit of maximum available displacement with economy of power would soon be reached, even should first cost be altogether neglected, as the *data* of the Paper which has been read abundantly testifies. On the other hand, the formula asserts that for a given length and a given speed, the power required varies as the displacement gains by adding to the beam or to the depth, and is propelled, ton for ton, at the same expense as the narrower vessel. Such increase is almost all available, and the first cost is little beyond the cost of the narrower vessel; therefore, the wisdom of adopting the shorter, cheaper, and handier type of armour-clad vessels appears to be incontestible.

Mr. Robert Rawson: I will make one or two observations, and will preface them with this remark—that I make them, and wish them to be received in the same light as that was received

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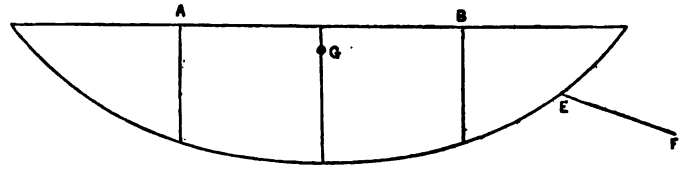
in connection with a very learned astronomer of days long by. When he was gazing at the stars above, he neglected to see the little ditch beneath him, which was pointed out to him by a very humble thinker. In what I have now to say, I wish to be in the position of that very humble thinker, and those who have gone before to be elevated to the position of that great thinker of antiquity who taught us how to grasp the height of the Pyramids without the rule and compass. A great deal has been said about the resistance of vessels, and, in my opinion, too much cannot be said respecting it. It requires a great deal of money, and a great deal of expense, to ascertain and analyse it. As far as I have been able to gather, that resistance has only been considered in its intensity, which is a very important feature to view, namely, the resistance opposed to the progress of vessels in water. But there are two other elements connected with that resistance which I am sure will be appreciated by an audience of this description. Besides the intensity, there is the direction and position of that resistance—elements which I have not heard discussed to-day. I do not believe we have any experiments which will give the designer of a ship the position of the resultant of resistance in the fore-part of the ship. But waiving that question, and taking that position, when it is found, to be of some importance, which I shall be able to shew is the case, I will, if the Chairman will permit me, come to the board and explain the position which I am about to take. But before doing so, I will repeat what I have often before stated, that I like, if possible, to agree with everybody; but I unfortunately disagree this morning with a statement made by Mr. Scott Russell, to which I will refer for a few moments. As far as I have gathered from what Mr. Scott Russell stated, he said that the midship, between the bow and the stern had nothing whatever to do with the intensity of the resistance of the water to the progress of the vessel. I think those were the words used by him. If that is the case, I would observe, from my recollection of reading the experiments made by Colonel Beaufoy some thirty years ago, that experience is directly opposed to the proposition. I believe, however, that when the length between the bow and the midship attains to a certain dimension, or a certain length, it is probable that it may not influence the resistance; but taking the various lengths of the ships that are used in practice, and taking the two limits that are used—that is, the short ship of Mr. Reed, and the long ship, as the *Warrior*,—I think that the length of the ship will have considerable influence, not on the direct resistance in front of the vessel, but the after part—the after resistance as it is called—and will very much influence the cost of the motive power employed to propel that vessel through the water. Now one word with respect to the importance of the position and direction of the resultant of the resistance. Suppose this diagram to represent the longitudinal section of a ship immersed in water, and the midships to be between the lines A, B, and G, the centre of gravity of the ship. If the direction of the resultant of the two forces—*viz.*, the motive power employed to propel the ship through the water and the resultant E F of the resistance—be such as not to pass through the centre of gravity G, in this case, the active force applied to move the ship may increase the passive force, *viz.*, the resistance to its progress by depressing the ship in the water. It is on this ground that the position E of the resultant of the resistance becomes important, and this position and direction evidently depend upon the position and direction of the motive power applied. There is a probability that such an effect which is here indicated took place on the trial of the *Hercules* in



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Stokes' Bay, therefore rendering Mr. Reed's comparison with the *Warrior* class less favourable than it would have been had the motive power been better applied.

Captain De Horsey, R.N.: My remarks will be very few and short, as I know the time is far advanced. I am in favour of short ships, and wish to protest against the principle which I have heard suggested to-day, of adding a middle body to a ship, by way of making her capable of carrying more, without any corresponding alteration in the entrance and run. If a ship requires more displacement to carry her coals, surely that displacement should be put in throughout the whole ship, and not be put in her in a straight line amidships.

Mr. Scott Russell: I did not say that it was to be in a straight line.

Captain De Horsey: I understood it to be suggested that the bow was to be the same, but that the middle body was to be added to.

Mr. Scott Russell: Yes, that is quite true—the middle body is to be added to, not in a straight line, but in a nice gentle curve.

Captain De Horsey: I have some little personal experience as to the way in which a vessel is impeded in her progress through the water, by reason of the friction on her sides. My brother officers, who have sailed in long ships, will bear me out in saying that in light winds, under sail, when trying to save our coals, the long ships are stopped and impeded very much by the friction on the sides, when the resistance to the bow is next to nothing. The speed is stopped by the friction, and you lie like a log of wood in the water. I cannot think that the principle of having a straight midship body is a good one; but that where a vessel's bow ends, her stern should begin.

Captain R. A. E. Scott, R.N.: It may be interesting to many gentlemen present if I give some details which I have just received from various officers with reference to an eight day's cruise of the *Hercules*, which has lately run out to Lisbon. They say that she is the easiest and steadiest vessel they have ever been aboard of; and those who have before spoken against Mr. Reed's vessels, will willingly admit that he has this time produced a very easy and steady gun platform. They say that they have seen nothing to equal her in handiness, and that in sailing she seems to be second only to the *Warrior;* and indeed that her whole performance has been most satisfactory. I thought it might be interesting to those who take an interest in this subject if I mentioned those few facts with reference to the *Hercules*. Having been with the *Bellerophon* myself, when in command of a very small ironclad, I have had an opportunity of seeing the performances of that vessel, and therefore can bear testimony to her qualities. Her handiness, and power of turning quickly, were, apparently, very great. Under sail, she did not act so well as she might otherwise have done, in consequence of her balance-rudder. But the divided balance-rudder now given to the *Hercules* appears to have got over every difficulty. You have, on the one hand, a rudder with a large area, on the balance principle, giving power of turning quickly, which is so essential in action, under steam; and on the other hand you have a rudder which, with the fire-part fixed, has the steering qualities which are essential in sailing. The captain of the *Achilles*, one of the finest ships in the Squadron, and eminently a long vessel, gives it as his opinion that the *Bellerophon* is a most effective war vessel, and more effective than his long ship. Some remarks have been made upon the expense of keeping these short vessels steaming. No doubt the expense would be very great if you

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were always to steam ahead at full power. But why should you be going on ahead in that way? You do not require it in the Channel Squadron, or when cruising elsewhere. I think therefore that argument wholly fails. In future warfare we shall be able to take our store vessels with us; we shall be able to take coal vessels with us; and hence the Squadron can be kept together, always ready for any eventuality, the ships kept going at slow speed, unless it be necessary to perform evolutions. And it is short ships alone upon which you can rely to perform such evolutions efficiently. I have only one further observation to make, and that is with respect to the double screw, because it seems to be thought that the double screw is the panacea for all evils. There never was a greater fallacy. With a shallow draught of water, double screws are, no doubt, to a certain extent effective; but with a deep draught of water they are comparatively ineffective; and no war-vessel with double screws can be so serviceable with a deep draught of water as she would be with a single screw. I will not touch upon the vessels which are now going to be built, because my opinion may be in opposition to that of many gentlemen present; but, as a naval officer, I have no hesitation in again saying that short ships are much superior to long ships for the ordinary purposes of war.

Mr. JOHN GRANTHAM: I sincerely regret that the discussion should be cut short, as it must necessarily be, having regard to the time, when so much valuable information would be gathered by sifting such a subject as this, as far as practicable. Whether all the points and qualifications connected with war-ships are so entirely different from those connected with the mercantile marine, as to make such a prodigious variation as is now advocated and strongly recommended and practised in the navy, is a question of the most vital importance. With regard to the mercantile marine, we require to carry weights; we require to have the best possible sea-boats; we require to have handy vessels; and we require that the vessels should be worked with the greatest possible economy. All those four elements are equally required in the navy. Why it should appear that ships, so totally different, as now constructed should each of them have, or profess to have, requirements so exactly similar, is very striking indeed; and I feel that this question is in reality left half way, and is not half investigated or discussed in leaving it in this position. I am sure there are false grounds on one side or the other; I am sure there are erroneous figures and results somewhere.

Mr. REED: Can you tell us where, Mr. Grantham?

Mr. GRANTHAM: The great question, and the question which of necessity involves so very much difficulty, is to find out where they are. I do not belong to the Navy—happily for me; therefore I do not propose to go into all the questions relating to the details of a fighting ship. But I have had some experience with regard to other ships, and have had a great deal to do with them, and wish to bring common sense to bear on the subject, and this tells me that there is nothing so remarkably and essentially different in the qualification of the two classes of ships, as to make such a vast difference in their construction and their proportions. I feel it impossible to enter into this question further than to ask all present to think seriously over this question: Why should there be this tremendous difference between vessels which have to encounter so many things in common? I cannot see that there is anything so very peculiar about a war-ship as a ship which makes it so essentially different from a merchant ship. They are, in my opinion, much more similar in their requirements than is generally supposed. The effort seems now to be, to make the world believe that they are essentially, if not totally

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different. I believe, from all that I have seen, that they are generally and substantially similar; and I see nothing whatever to warrant the great distinction that is sought to be made.

Captain E. A. INGLEFIELD, R.N., F.R.S.:* Happily, I *do* belong to the Navy, and also lay claim to a little common sense. I may state that I have lately been cruising in the Mediterranean with the *Warrior*, and have seen the advantages of a short ship over a long one in cruising. One great feature is extreme handiness. I am satisfied, that for the purposes of war, the short ship will have great advantages over the long one. The ramming bow, which is being introduced into our Navy, is one of the greatest and most important elements of power applicable to naval warfare; and for any such purpose as that, it seems to me that a short ship manifestly has considerable advantages over all others. I am therefore bound to give my testimony in favour of the short ship.

The PRESIDENT: It is with much regret that I feel myself compelled to interpose; but this discussion (which has been a most interesting and important one) has so very far exceeded the usual limits of time, that I hope it may be brought at once to a close, unless Mr. Reed may wish to reply to any of the observations which have been made with reference to his most valuable Paper.

Mr. REED: I confess I feel some reluctance in occupying further time with reference to the Discussion upon my Paper, especially as so much indulgence has been extended towards me. But my position is a peculiar one, and it becomes almost a necessity for me to reply to some of the observations which have been made, and which affect not only my own views, but Her Majesty's Navy. In the outset, I may say that I am perfectly staggered at the statement which fell from Mr. Scott Russell about the objects influencing the design of the *Warrior*. Certainly I must say that I have learnt to-day—and he was quite right in assuming that I should learn to-day,—for the first time, that the *Warrior* was designed to carry 2,500 tons of coal. I can only say, that if that was in reality an element in the design of the *Warrior*, it has been most miserably fulfilled. The quantity of coal provided for in the design of the *Warrior*, which was sent out by the Admiralty to the contractors, that is, the quantity put down as her supply, was 937 tons. The greatest quantity of coal she has ever had on board of her is 810 tons, and her normal supply is 800 tons. The weight of the *Warrior's* engines and boiler is 920 tons, which, added to her 800 tons of coal, gives a total weight for engines, boilers, and coal, of 1,720 tons. The total weight of the engines, boilers, and coal of the *Hercules* is 1,806 tons. So that the *Hercules*, being 55 feet shorter than the *Warrior*, carries nearly 90 tons more of engines, boilers, and coal; and although she carries a good deal of that, not in fuel, but in the form of economical contrivances for saving fuel, I have a right to infer, and am justified by the performances of the *Hercules* in inferring, that her steaming power is superior, measured by distance, to that of the *Warrior*. I very well remember the facts which were laid before this Institution as soon as the *Warrior* steamed into Lisbon. We know that the consumption of coal on that occasion was very large indeed, and the *Warrior's* power of steaming, over a certain number of days, was very limited. I am perfectly satisfied, speaking from the experience which I have gathered in the Navy, that with these economical engines, the *Bellerophon*, the *Hercules*, and the *Monarch*, and all those vessels, are capable of steaming for a greater distance than the *Minotaur*, and *Warrior*, and that class

* Now Rear-Admiral Inglefield, C.B.

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of vessel. That is a proposition which I lay down with the greatest confidence. I am aware that it is a proposition which may be denied and contradicted by reports, because the *Bellerophon* was for a long time without her superheaters working at all, and was labouring under other disadvantages from her peculiar engines; but however that may be, I am utterly at a loss to understand why so large a coal supply is accredited to the first vessel. Mr. Scott Russell has contended that there is something in the inherent nature of a long ship, or a ship with a long central body, which favours endurance. I am quite prepared to admit that; and at the same time that I make the admission, I may say that all my ships have much longer central bodies than the *Warrior;* therefore I take the credit, as I am entitled to do, of that advantage, if it be an advantage. The peculiarity of my vessel is, that I shorten the ends without taking away the middle, thereby getting the advantage which is so desirable. It is really not correct, as has been supposed, to say that the *Warrior* and *Minotaur*, and those ships, which were made long and large, not at all for the purpose of carrying coal, but for the purpose of carrying those excessive and useless weights, have the faculty of enduring or keeping the sea, or doing anything in any way which the shorter ship has not the power of doing. I have much pleasure in making that statement in the presence of every gentleman here. Nor can I believe that the *Bellerophon* was intended to meet a smaller class of enemy than the *Warrior*. She was intended to meet the same, if not a larger class of enemy, and in my opinion she is quite capable of doing so. With regard to the unarmoured length by virtue of which the *Warrior* gets such advantages as she possesses, that would disappear the moment you entered into action, for she would be liable to injury below the water-line, the water would get in, and that great advantage to which so much is attributed, namely the speed, would be destroyed. Then, Mr. Lamport said that all experience was against what I had propounded, as a general rule. I take the liberty of saying that the reverse is the case. The French, who are a very capable and scientific nation, have never thought of departing from the short iron-clad ship, and they have never built a long one. The whole experience outside of England, with reference to armour-plated ships, is entirely in favour of my method of construction; and the effect of the construction of the long vessels, which I, with much effort, and great disadvantage in many ways, have been nevertheless permitted to bring to an end, would have been merely to eliminate from our navy the element of great handiness, in such a manner as to place us at a serious disadvantage with reference to the navies of Europe. I may with some amount of confidence say that Mr. Lamport contended for a proposition which will not be borne out by naval gentlemen present, when he argued that a big ship did not require a larger crew than a vessel of a smaller description. I deny that emphatically. I say that the demands of a man-of-war do increase with the size of the ship. Even although you put the very same rig in the large ship as you put in the smaller one, you nevertheless require more men. There is a larger ship to be watched, worked, and kept clean, and a greater number of men are necessarily required. Then with regard to the question of double screws; Mr. Lamport put it forward as rather a terrible thing, and a thing calculated to excite some alarm, that we should have secured the handiness of the *Bellerophon* and *Hercules* by single screws, when we could have done it so much better with double screws. Now, first of all, I deny that you could produce anything like the handiness of the *Bellerophon* or the *Hercules* with double screws. Upon this question, namely, the question of handiness, I should state that I have been down the river repeatedly in twin-screw vessels; and although they have been under the most favourable circumstances, down by the stern, up by the head, and nothing on board, I have never yet seen a twin-screw vessel, no matter under what conditions, that can turn with anything like the handiness of the *Hercules* at

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load-draught and full speed. I may also say further, as touching the question of double screws, that in fact a very great advantage in the use of double screws arises from the circumstance that they will *not* steer so well as people will have us imagine; because if anything happens to one screw, you can go on propelling with the other. I know a case in which an accident happened to one of the screws, and 2,500 miles of the voyage was made with the other screw. One of the greatest advantages of twin screws in vessels without masts and spars, is that they are able to steam efficiently ahead with one screw, and that the one screw has not the power of slewing her rapidly round. Lord Lauderdale asked if the short ship had the same power of steaming against a head-sea as a long one, and mentioned that there were seas in which a short ship was at an extreme disadvantage. I entirely admit the position taken by the noble Lord; but I may add that there are, on the other hand, seas in which the short ship has special advantages which a long one would not have—those, for instance, in which the *Minotaur* would make one bob, as it is called, and take some hundreds of tons of water upon her deck. I say that both the long and the short vessel have their advantages and disadvantages. The long ship, both in pitching and rolling, will sometimes derive advantage from her length, and sometimes disadvantage. On the other hand, the same thing applies to the short ship. According to the character of the waves with which she is engaged, she will gain advantage or disadvantage as the case may be. With regard to what was said by Captain Selwyn, I am afraid he did not accurately apprehend the nature of the curves. They have nothing whatever to do with the deck curves. One curve represents the displacement, and the other represents the weight of the ship. It is not the curve of the deck line at all.

Captain SELWYN: I quite understood that; but what I was anxious to know was, whether there was greater displacement on the ship pitching?

Mr. REED: I apprehend there can be no doubt that as the ship pitches, she gains greater displacement. Of course every one must admit that it is not a wise thing to take a floating body, and suspend a weight of 400 tons fully 100 feet away from her balanced portion, in order to get certain qualities; but I do not think I need address myself further to that point. Mr. Grantham made a speech, which has the great advantage to myself of removing from my mind any further doubt as to how it is one cannot get these things properly understood by the general public. Here is a gentleman whose whole life has been spent in connection with ships, and who really is a scientific writer of great repute in connection with the construction of ships; yet notwithstanding my Paper, and within an hour after its being read, he declares himself incapable of seeing any substantial difference between the character of a mercantile ship and an iron-clad war-ship! If Mr. Grantham, with all his ability, experience, and knowledge upon this subject, is incapable of seeing the difference between a ship into which you have to put certain weights, and a ship where, if you increase her length, you increase the armour which is put upon her, I can only despair of those who are less acquainted with the subject than Mr. Grantham being able to see the distinction, and can only expect that I shall be held up as an object of pity in the future, as well as in the past. But the principal point, and that upon which I rose to speak, was with regard to the coal supply. I wish it to be understood, and repeat that there is no deficiency in the steaming power of the later iron-clads. Taking into consideration, as we must, their engines, and their means of economising, they are all of them superior, and not inferior to the earlier iron-clads.

The PRESIDENT: I think I may say of this discussion, as I said at the close of our proceedings yesterday, with regard to the discussion we then had upon the subject of floating docks, that such

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discussions are strong and most admirable illustrations of the value of such an Institution as this, where such important matters can be debated by such competent men. I am sure the Meeting will not pass upon me that vote of censure to which I should otherwise be fairly entitled, for the indulgence with regard to time which I have extended towards the parties; but that all will agree with me in saying that our time has been well spent, and that we are very much indebted to Mr. Reed for the ability with which he has brought this subject before us. The next Paper on the programme for this morning is one "On "a New System of Iron-clad Vessels," by Herr Josef Romako, Chief Constructor of the Austrian Navy, and a Member of our Institution; but I am informed that we have not the Paper here, consequently it cannot be read. I understand from our Honorary Secretary that a translation of a Paper by Admiral Paris has been substituted for it; but I think you will agree with me that a substituted Paper, of which we have had no notice, (although when it comes we should be happy to hear it) ought not to be permitted to interrupt the course of our proceedings to-day. I will therefore call upon Captain Inglefield to read his Paper.

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ON THE HYDRAULIC STEERING GEAR, AS BEING FITTED TO H.M.S. "ACHILLES."*

By Captain Edward Augustus Inglefield,† R.N., F.R.S.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; the Right Hon. Sir John S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

At the request of your Council I have prepared a Paper on my proposed plan of hydraulic steerage for large ships in Her Majesty's Navy.

The result of a report by Sir William Armstrong and Mr. Penn upon my invention has been an order to fit H.M.S. *Achilles*, and I am, therefore, able to place before you some drawings of the apparatus in question on the Admiralty scale of the ship.

I assure you that though I feel much honoured in being called upon to submit my plans before this Institution, composed as it is of the most eminent engineers, shipbuilders, and naval officers of modern days, I have some apprehensions as to my ability to satisfy you on all the mechanical details, not as regards their action, but regarding their suitableness of application.

I feel assured that I shall only be met by the fairest criticism, and that *you*, as practical engineers, will be indulgent to one whose profession is sailoring, but whose ideas are being carried out by the skilled engineers, Messrs. Renton and Messrs. Kitto and Brotherhood.

Perhaps it may be in the minds of some present that any improvement upon the ingenious arrangement of steam steerage now fitted to H.M.S. *Northumberland*, and being supplied to H.M.S. *Monarch*, is uncalled for; and if an hydraulic is to be employed, *that* now on board the *Minotaur*, as arranged by Messrs. Humphreys, was all that could be demanded from this form of power; but in both these, nay in all

* Received 19th March, 1869. † Now Rear-Admiral Inglefield, C.B.

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forms of steerage in which manual labour was not the first motor, steam-power in some shape or other has been employed.

I have sought to dispense with steam, and to employ some power under all conditions available, and equally uniform in its action and application.

When inspecting the *Minotaur* on her return from the first experiment with the steam hydraulic I was shown the steam donkey in the engine room, and told that to ensure its action at short notice it was kept at work pumping water to waste when not required for the hydraulic; that it was naturally only available when steam was up, and at the proper pressure. Moreover, that to move the helm a long lever, worked by two men, was employed for starting the directing slide.

In the *Northumberland* there exist the usual tiller and ropes, but the application of steam is employed to move the barrel around which the tiller ropes are coiled.

I am informed the certainty and rapidity of action are all that can be desired.

Considering the matter in a practically nautical point of view, I believe one of the greatest desiderata in any form of steerage-power is to place it and all appertaining to the rudder as nearly as possible beyond the reach of shot, and to depend as little as possible upon any power which is not always available and constant in its action.

In an excellent Paper read by Mr. Barnaby before this Institution on March 26th, 1863, he puts four principal questions for consideration, *viz.*: "First, with regard to the "ordinary rudder in single-screw ships, can any improvement in the ordinary rudder, "either in its form and dimensions, or in the mode of applying power to it be expected to "give us such facilities in steering as the exigencies of modern naval warfare demand; "and if such improvement may be expected, in what direction is it to be sought?"

To meet *this* demand I have suggested a form of hydraulic steerage which I have designated *hydrostatic* hydraulic in distinction to *steam* hydraulic, the power I employ being the hydrostatic pressure due to a column of water at the lowest depth in the bottom of a ship at which a pumping engine can be placed. Having said thus much, I daresay the process of adaptation will readily present itself to the minds of many present, therefore little more is necessary than to describe the principal formation and action of the different parts employed.

Allowing for friction, I will roughly estimate the pressure of the water in the power cylinder when admitted through a suitable Kingston valve at a draught of 20 feet at about 8·66 pounds on the square inch. This force is allowed to exert itself against a piston of the area of 36 inches, and by its action to work a reciprocating pump. (*See* Fig. 1.)

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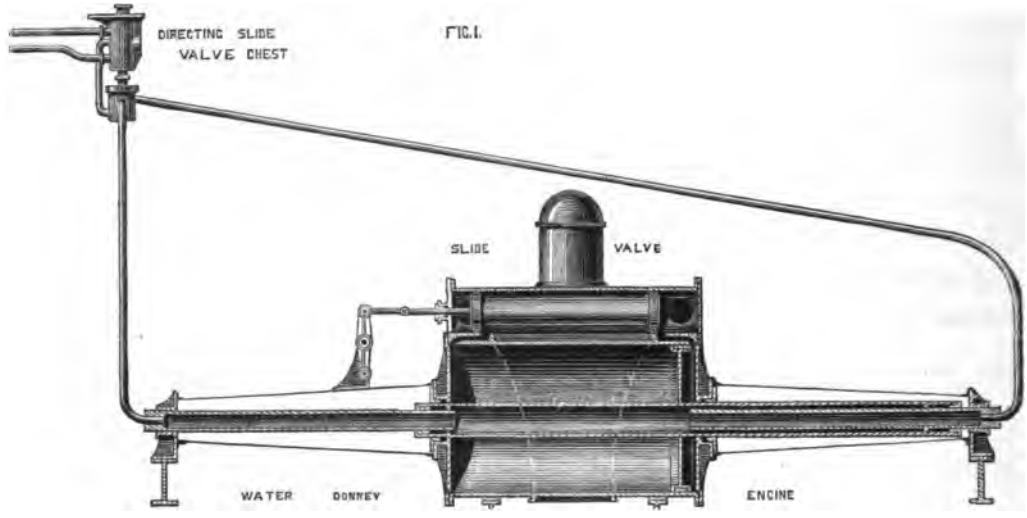
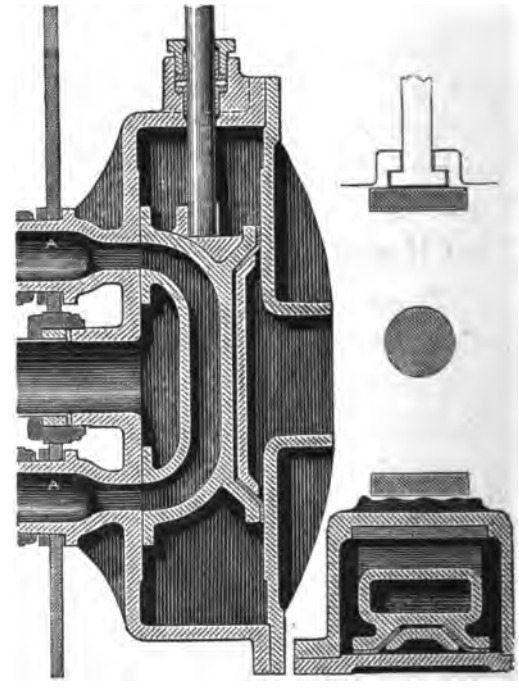
From this pump are led two wrought-iron 2-inch pipes, which conduct a constant and independent body of water to two cylinders placed on either side of the lower tiller,



and connected therewith at a distance of 4 feet 6 inches from the rudder head, with a suitable arrangement for connecting and disconnecting. In Figs. 2 and 3 are shown the slide box, which contains the directing slide, and it is by the action of this slide, which is moved by a rod, and small wheel in the pilot house through a distance of about 5 inches, that the engine is set in motion and the hydraulic presses brought into play.

FIG. 2. FIG. 3.



I will briefly recapitulate. The Kingston valve having been opened, free access of the external column of water is opened to the pumping engine, but no movement of the helm takes place until the slide, which may be made to lock the water in the two tiller cylinders, has been moved so as to admit of a change between them in the direction desired, and so directed by the movement up or down of the D-slide.

An indicator placed before the helmsman shews the amount of movement of the helm, and the moment the tiller has been placed over to the desired angle the slide is made to lock the water into its position, and the helm is at once rigid.

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Let us suppose the helm to be hard-a-port, and it is desired to right it, the centre spoke of the miniature wheel (which is only capable of moving through an arc of little more than three-fourths of its circumference) is placed amidships, and then the slide, which is hollow, immediately opens a free communication between the two tiller cylinders, and the resistance of the passing column of water acting on the rudder forces the helm amidships, and by its action drives the constant water from one tiller cylinder to the other until they are in equilibrium; by this method no power is expended (under any circumstances of the ship passing through the water) in righting the helm, though if it be desired to do this with greater rapidity, the pumping engine requires only to be properly directed, and the tiller may be pumped over through the whole arc.

Now, as to what becomes of the water, which, having expended itself of its power, has to be got rid of.

Two plans have been suggested: my first was to confine it in a tank formed in the double skin of the ship, and thence to pump it overboard by a single-action plunger pump to be worked by an eccentric on the screw shaft immediately above the tank. The engineer of the *Achilles* and others seem to think this unnecessary, and that it may be at once conveyed into the bilges, and there drawn off by the steam bilge pumps. Accordingly the *Achilles* is being so fitted. Now, with reference to the volume of water necessary for the ordinary demands of steering a ship, the water thus expended may be considered comparatively small, especially when it is remembered that the *Warrior*, when steamed at the rate of 14 knots, admits about 36 tons or 720 hundredweights of water per minute into her condensers, and has to dispose of it by her pumps either overboard or as feed-water.

Roughly estimating the volume of water necessary to put the helm of the *Warrior* hard down four times in the hour, it has been calculated that there would be expended for my hydrostatic power cylinder 44 hundredweights once in 15 minutes; the ratio is, therefore, 240 to 1, that is, 240 times the quantity of water is admitted into the condensers that would be admitted into the hydraulic under this extraordinary demand upon the helm. This, if thought advisable, could be retained in a closed tank, as suggested before (which might thus correspond so far with the condensers) and from thence be either withdrawn by the bilge pump, or by what I at first proposed, a common plunger pump worked by an eccentric fitted in a convenient position on the screw shaft. The foregoing calculation is made supposing the helm to be pumped over through the whole arc; but by the arrangement of the hollow slide there is an economy of nearly one half the volume of water thus necessary, and a further saving of power and time in the action of the pump at reduced speeds is effected by the following process:

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I have, in Fig. 4, a drawing of a three-way cock, which has been constructed by my ingenious friend, Mr. Renton, an engineer to whom I am indebted for some novel arrangements of valves and fittings. This three-way cock is situated in a convenient position near the tiller cylinders, and easily accessible to the quarter-master; by its use a saving is effected, at slow speeds, of the power I *must* employ at *full* speed to ensure rapidity of action. The tendency is simply to reduce the area surface of the pistons in the tiller cylinders, and so to reduce the volume of water necessary to be employed to give them full power. By the combined action of the hollow D-slide and the three-way cock, more than two-thirds of the whole volume of water (which I at first spoke of) will be saved on a long average. The power which has been calculated as necessary to be exerted at a tiller of 4·6 radius, is about 35 tons, the length of stroke being about 5 feet. I shall be asked by naval men what arrangement I have made to provide for steerage, should the hydraulic be disabled? In reply, I point out that the original tiller existing still *in situ*, the tackles may be shackled on, and the ship steered by wheel and ropes in the usual manner, at a few minutes' notice. The gear I employ for connecting and disconnecting the hydraulic is, I think, simple enough. It may thus be described: a movable fork (Figs. 5 and 6), sliding on the tiller by means of a coarse-threaded screw, is made thus to grasp a steel pin on an iron block, to which the two piston rods of the tiller cylinders are keyed. By this arrangement, in case the ship should strike the ground aft, the tiller is lifted clear of the hydraulic apparatus. The wheel, which is placed in the pilot house, is arranged so as to move exactly in the same manner as the ordinary steering wheel, so that any seaman can steer thereby, with the difference only that he may move it with one hand.

FIG. 4.

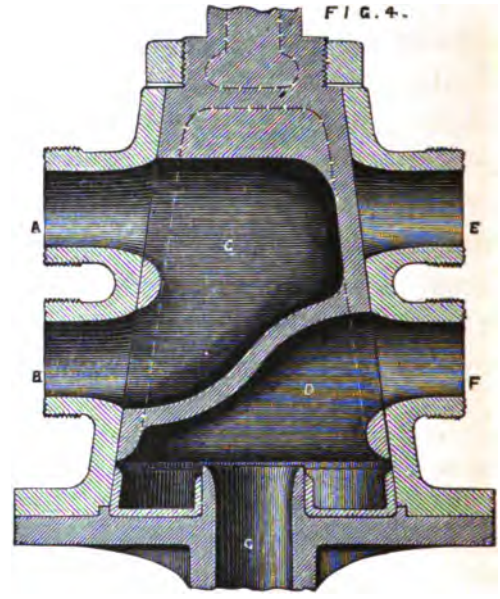

FIG. 5.

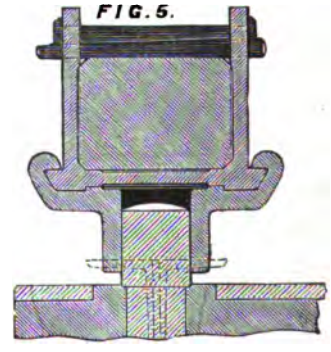

FIG. 6.

Mr. Barnaby, in his Paper read before this Institution, makes the following remark, *viz.*, "that the *Black Prince* was on one occasion turned completely round in 8′ 33″, the rudder being over to 28°; but in order to hold it there it required ten men at the wheel,

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and thirty men at relieving tackles, no less than forty men being employed at this operation. This," says he, "is of course an extreme case, but it serves to shew that an invention which promises to reduce the number of men required to one or two has great claims to consideration;—an advantage which is of slight consequence in small vessels assumes in these large vessels very great importance." I may instance that in the *Prince Consort* (an iron-clad I lately commanded in the Mediterranean for nearly two years) it required eight men crowded into the wheel, and twenty-eight at the relieving tackles in my cabin to get the tiller over in a minute and a half.

The advantages I claim for my system of hydraulic steerage are:—

Firstly, the employment of a vast accumulator, *viz.*, the exterior column of water, which, admitted through the bottom of a ship of large draught, is made to work an engine whereby a water rope (if I may use such a simile) rove through a gearing of hydraulic cylinders at the tiller head is made to draw the helm over in either direction.

Secondly, as this power exists under all conditions of a ship afloat, and is constant and uniform in its action, I can avail myself of it at any moment in large or small quantities with certainty of immediate action, however long it may have been unemployed. And it is in this particular that I claim an advantage over the steam engine to do the same work. Moreover, the engine-room space occupied by a steam pumping engine is saved by the employment of a water pumping engine, for the latter is placed on the keel of the ship at a spot wholly unemployed, and not adapted for any other purpose.

Lastly, the incompressibility and incondensibility of water, as compared with steam, is another feature which I hope may be deemed, by those best qualified to judge, a feature worthy of consideration.

I have now brought before this grand jury the offspring of more than five years' thought and labour—a labour accompanied with much discouragement and opposition, many disappointments, and no small expense.

Your verdict may seal the fate of its future. A first experiment may be successful, but the far-sighted man of science, and practical seaman, or mechanic, may blast the fame of an invention by one practical objection, or even doubt. It will be for me, in this case, to endeavour to meet, as best I may, such objections, should they now arise. It remains only to thank you for your kindness in permitting me to bring my plan before you in this public manner.

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DISCUSSION.

Rear-Admiral Astley Cooper Key, C.B., F.R.S: The question which Captain Inglefield has brought before us is of such great importance to all nautical men, that I hope he will pardon me for asking a few questions just to make it a little more clear to those people who, like myself, have not quite understood the manner in which the power is obtained in the first instance. According to what Captain Inglefield has shown to us, we have on board ship, either at sea or in harbour, by night or by day, whether the ship is moving ahead or at rest, an inexhaustible source of power. If he can, by opening a small hole in the bottom of the ship, produce a power of 35 tons, working at the level of the water-line of the ship, it only requires a little labour to apply it for all that is necessary on board ship for working our guns, and as an auxiliary power in working the ship generally. But what I want to understand more clearly is this. If I understand Captain Inglefield rightly, he obtains power by a small pipe and a valve 20 feet below the surface of the water, the pipe admitting water into a cylinder having a piston 36 inches in area. The power or pressure exerted on the piston is very large; and as I understand, power is obtained by the piston being pressed forward in the cylinder, creating a pressure upon the water the other side of it, and forcing a body of water through a small pipe to the rudder-head where the work is done. It appears to me to be very clear that although the pressure upon that piston is very great, in proportion to its area, yet as the water leaves the cylinder and goes through the small pipe, the pressure is reduced again to the amount of the area of the pipe, as compared with the area of the piston, and that it has then to raise the water, and has the same pressure opposed to it in moving through the cylinder as has been brought to bear upon the piston in the first instance. It seems to me that the weight of the water inside the ship, due to the height of 20 feet, is the same as the weight of water outside the ship, from which the power is obtained. It is not quite clear to my mind, but it seems to me that that is the effect of the invention as explained by Captain Inglefield.

Mr. John Scott Russell, F.R.S.: I should wish to understand Captain Inglefield's proposal a little better than I do. First of all, I quite understand that he has at his command a reservoir of pressure; because, allowing his ship to draw we will say 25 feet, he can easily have 18 feet or 20 feet for the purpose of obtaining pressure. We know that every 2 feet high of water will give a pressure of 1 pound; therefore if Captain Inglefield has 20 feet of water over his cylinder, he has evidently got 10 pounds pressure. So far I think I follow him. Perhaps Captain Inglefield will say whether I am right in that?

Captain Inglefield: Perfectly so. I must apologise for my want of clearness of description.

Mr. Scott Russell: What I wish to be informed upon, is this. I quite understand that this pressure is exerted upon the piston of a cylinder. Is it the piston of the same cylinder by which the water is pressed up to its work?

Captain Inglefield: No—it is virtually a different engine, inasmuch as there is a pumping engine inside, the water represented by the pink in the diagram being constant, and that represented by the green being changeable. Admiral Key's question may be answered in one word, by saying that I simply employ water instead of steam to work a donkey engine, and hydraulic pumps.

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Mr. SCOTT RUSSELL: I think we begin to understand one another a little better now. But the point which Captain Inglefield must clear up in our minds, in mechanism, is this: We all see that there is the height of 20 feet applicable for the pressure. But we see, also, that Captain Inglefield carries that up to the top; and therefore Admiral Key says, will not that counterbalance the outside pressure? I will venture to answer that in this way. If the pressure on the second cylinder comes from the piston which presses upon the first, then Captain Inglefield loses all the advantage he gains; but if, on the contrary, he detaches the first cylinder from the second, so that the pressure upon one piston has nothing to do with the pressure on the other, then he may be able to get a great amount of concentration of power in the second piston out of the first one. Does Captain Inglefield do that?

Captain INGLEFIELD: Yes. The pressure is converted from 8 pounds to 600 pounds on the square inch.

Mr. SCOTT RUSSELL: Then I now understand Captain Inglefield, though I did not understand him before. I now perfectly understand how Captain Inglefield can, with a pressure of merely 10 pounds of water, convert that into a pressure of 100 pounds in his second cylinder. He has only to make one piston very small, and the other piston very large, to get the increase of pressure in that proportion. Then the next point is this: we have now got the water engine doing the work of the steam engine. But it does it by discharging the water into the ship, and we have now got to pump that same water, by steam, out of the ship, against the same head of pressure. We then come to the next stage, which is, that we have to give back all the pressure that we have got from the water outside, by a steam engine, to the water outside again. That is true, is it not?

Captain INGLEFIELD: Yes, that is so.

Mr. SCOTT RUSSELL: Therefore comes the natural question to us—Why do you, Captain Inglefield, take merely this outside pressure which discharges itself into the ship, and pump it out again by the steam engine; instead of adopting, what seems to us the more easy, natural, and convenient method, of just employing the donkey, or any other part of the machinery of the ship, to create, by the simplest possible means, the pressure you want, where you want it? That is really the critical point of the case. You must excuse me, as a mechanical man, if I do not quite see the reason of your aversion to take, what seems to us mechanics, the more natural course of using the steam engine which is already aboard, to produce a constant pressure by which by the easiest of mechanical means we can make an infinite reservoir in the ship, put it where we like, and have it always at our command. No doubt there are important reasons, though I have not yet been able to see them. If Captain Inglefield would explain why he prefers the method he has suggested, we should then be able to see what was the advantage of using this outside water.

Captain INGLEFIELD: I hope I have made myself clear and intelligible with reference to using the hydrostatic pumping engine, as simply an engine which is worked by a pressure of water instead of a pressure of steam?

Mr. SCOTT RUSSELL: I quite understand that.

Captain INGLEFIELD: Then the next question in fact amounts to this—Why do not I employ the steam engine, which has to pump the water out, to steer with? I answer—For several reasons. The

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Warrior was fitted with an hydraulic steering apparatus, and made several experiments during a three months' cruise. It was found that the steam engine could not always be made available, from want of steam. It was found that it was not ready when wanted, and did not exert itself at the moment and instant required. Thus the system of having an independent working engine, worked by steam, was found not to be convenient for the purpose. To meet this difficulty, an internal accumulator was suggested. Two large cylinders were fitted, loaded with 5 tons each. These were pumped up by the engine, and there was an accumulator always ready at any moment to be turned on the tiller cylinders, and so to commence the action that was required without a moment's delay. There was therefore the steam donkey engine, pumping the upper accumulators to do the work which I propose to do without anything but the external accumulator. By my arrangement, I dispense with a wheel, with tiller ropes, and have a tiller only 4 feet 6 inches long. I therefore dispense with a great deal of gear, which is exposed to shot in action, and in place of it I put a rod from the pilot-house to the ship's hold, and that is the only gear to represent the ordinary wheels and tiller ropes in the usual steering apparatus. More than that, in all ships you are obliged to keep from four to six men at the wheel, who, as sailors know, may for hours have nothing to do, but move the wheel a few spokes; still they must all be there—in fact, a gun's crew. I can relieve all those men; I have always got my power equal to forty men at a moment's notice, and worked by one individual. I do not know whether I have quite met Mr. Scott Russell's objection, but what I say is this—There is the power ready to be exerted at a moment's notice. The water is pumped up by the bilge pumps; and if any necessity arises for water being turned into the bilge in any quantity, such as would be the case where the helm had to be put down four times in an hour, they will then have to draw off larger quantities of water, when during the other part of the day they may not have to draw off as many pints of water as they then draw off gallons.

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ON THE STEAM STEERING APPARATUS, FITTED IN THE "GREAT EASTERN," AND H.M. SHIPS "NORTHUMBERLAND" AND "MONARCH."*

By JOHN MAC FARLANE GRAY, Esq., Shipwright and Engineer Surveyor to the Honorable the Board of Trade.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; Vice-Admiral Sir EDWARD BELCHER, K.C.B., Vice-President, in the Chair.]

IT is now more than half a century since the first establishment of Steam Navigation in this country, and during that time great improvements have been effected in the construction and propulsion of steam vessels; but the appliances for steering large steamers are still almost identically the same as those employed in the wooden ships previous to the introduction of steam. It is remarkable that this should be the case, considering that the modifications in the form of hull, the increase of speed, and the absence of sails, all resulting from steam propulsion, render the steering not only of more importance, but at the same time more difficult. In some of the armour-plated ships in the British Navy, it requires nearly a hundred men to put the helm hard-over when the vessel is going at full speed; and except with twin-screws the action of the rudder is the only force that can be applied to change the course of a steam-ship. The handiness of the vessel and its safety, especially in a war steamer, depend upon being able to manœuvre it quickly; and hence it is of the first importance that a steamer should be provided with as much steering power as possible. This has hitherto been limited by the power at command for moving the rudder; and in the merchant service the increase of force required has been provided at the expense of time by introducing gear with a greater mechanical leverage. Where collision is imminent, the power required for quick steering being wanting, the engines have to be reversed, whereby the danger is often increased; the vessel continues to advance even after the engines are reversed, until her way is stopped; and it requires some time to reverse, first the engines and then the motion of the ship itself. Under such circumstances the best

* Received 10th May, 1869.

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security would generally be found in a quick steering gear, which would quietly and with certainty alter the ship's course, without the confusion always created by a sudden order to reverse at full speed.

The work of steering a ship is one which requires in regular sailing only a small expenditure of power; but it is necessary occasionally to apply a great amount of force for the purpose, and arrangements should be made that this may be applied at any instant without distracting the attention of the steersman or requiring any special exertion on his part. The whole of this force, whatever it is, should be always at hand, and always on duty, so that there may be no loss of time and no uncertainty in its action.

With the economy of labour necessary at sea, the amount of manual power required for steering is not always available at the moment when needed, and sometimes there is only half the steering power at the wheels, while the other half is employed in other parts of the ship. In a recent case of collision at sea one of the witnesses stated that, being on deck when the order was given for hard-a-port, and hearing it repeated a few seconds afterwards, he went into the wheel-house to help to put the rudder over. It is apparent that such a case ought not to occur at the present day, and the steering ought to be so controlled that no order should have to be given twice. Even indirectly this would add greatly to the safety of the ship, for it would free the officer in charge from the distraction of mind produced by the uncertainty as to whether his order was being obeyed or not, and would leave his whole attention free for the further orders required.

In addition to the want of power which has all along been experienced in the steering of large steamers, there has also been considerable risk of injury to the men at the wheels. They have had not only to put the rudder over to a certain place, but also to keep it there as long as required; and they have also to keep the rudder amidships when required. In general there is such an amount of slack in the gear that the rudder cannot be held steady in any position unless the water is exerting some force against it. When nearly amidships therefore, and in rough weather, the pressure on the rudder is continually changing from one side of the rudder to the other; and when struck by a wave on the opposite side, the rudder moves rapidly a short distance until it is checked by the steering gear. These changes are quick, and tiring to the men; and when the force of the wave happens to come suddenly in the same direction as that in which they are exerting their force, the wheels sometimes fly round, knocking the men down, or throwing them over the wheel altogether; and broken limbs and many fatal injuries have been caused in this way.

The steering of a ship is effected at the stern, which is the very worst position on

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the deck for a look-out; and this objection has therefore been met in two ways. In some ships the chains or ropes for moving the rudder are led from the stern to some more convenient station about the middle of the ship; and in others the steering is controlled from the bridge at the middle by telegraphing to the men at the wheels. The first plan is inconvenient, and exposes a long stretch of rope or chain to a great strain; and steering by telegraph, however well arranged, always involves a little delay, and is not so certain in its action as direct steering.

From these considerations it is evident that every steamship ought to have a quick and direct steering power; that this power should be always on duty, and always to its full amount; that it should be certain in its action, requiring no second order; that it should not expose the men to danger; and that it should be controlled from the bridge or other suitable station on the deck. The consequence is that in steamers over 1,000 tons burden these conditions can be fulfilled only by the use of steam power.

The want of a steam steering engine was from the first felt in the case of the *Great Eastern* steamship, but until 1867, the vessel was steered by manual power alone; and the danger to which she was exposed on a former occasion by the accident to her rudder stock was the result of want of power at the wheels, the men not being able to keep the rudder in check. The automatic steam steering engine forming the subject of the present Paper was designed by the writer, and constructed for the *Great Eastern*, by Messrs. George Forrester & Co. of Liverpool, under the inspection of Captain Sir James Anderson; and the following conditions were required to be fulfilled in its construction:—

1*st*.—The alterations on board the vessel to consist of additions only, and no existing appliance for steering to be removed or impaired.

2*nd*.—The steam power to be sufficient for moving the rudder at all times at a greater speed than had ever been attained by manual force.

3*rd*.—The steering to be controlled from the bridge by some means equal in efficiency to the existing telegraph plan.

4*th*.—The new arrangements to admit of men working at the wheels in order to assist the steam power if required.

5*th*.—The steam gear to be capable of being disconnected without interfering for an instant with the means of steering by hand.

6*th*.—The rudder to be held in any position by the steam gear without applying a brake.

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7th.—The engine to start without hesitation at all times, even after standing for a considerable period without acting.

8th.—The apparatus to be simple in all its parts, and requiring no special attendant or engineer.

9th.—The engine to be capable of being used as a windlass, if required, when disconnected.

The automatic steam steering gear actually constructed fulfilled all these conditions, and in several respects far exceeded the requirements. It is shown in Plate V.; Fig. 1, being a longitudinal elevation, and Fig. 2, a general plan showing its application on board the *Northumberland.*

The steering gear consists of an engine, A, Figs. 1 and 2, connected to the shaft of a steering barrel, B, at the stern, and controlled through a shaft, C, by a small steering wheel, D, at the bridge or conning tower. This wheel is so arranged that the steering wheels, EE, at the stern revolve turn for turn with it, and the steersman at the bridge directs his attention, not to starting or reversing the engine, but simply to steering the ship by the bridge steering wheel, D, leaving the engine entirely out of consideration. There is an index at this wheel, D, showing the position into which the rudder is required to be brought; and at the stern in the *Great Eastern* and in the *Monarch* there is another index with a director arm, which serves as a steering telegraph dial when steering by hand. There is also a spare controlling wheel, Z, aft, so that the steering by steam can be controlled from the stern if required. The steering barrel, B, the chains or ropes, FF, and the tiller remain exactly the same as before the alteration, and are worked direct by the steam steering engine.

The engine itself is of the simplest construction, as shown in the Plate, having a pair of cylinders working cranks at right angles; and the reversing, stopping, and starting are effected by an automatic stop-valve at H, a hollow cylindrical slide, covering both the steam and the exhaust passages, so that according to its position it can reverse the action of these passages, thus making the engine to go in either direction by changing the exhaust into steam passages and the steam into exhaust. The two slide-valves are the same in form and dimensions as this stop-valve, and are worked by fixed eccentrics set on the driving shaft, S, each at right angles with its crank.

The automatic stop-valve, H, does not work with the engine, but is controlled by the differential screw, I, which constitutes the self-regulating portion of the steering gear. The stop-valve is connected to the screw, I, by a rod and bell-crank lever, so that the longitudinal motion of the screw is communicated to the stop-valve. The pitch of the

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screw is 1¼ inch, and the range of its longitudinal travel is 2½ inches, being equivalent to two revolutions of the screw in its nut, which is itself incapable of longitudinal movement. This nut however is not held stationary from turning, but is formed in the centre of a mitre wheel, which is geared with an equal wheel on the barrel shaft, so that the nut makes one revolution for each turn of the steering barrel, B. The differential screw, I, has a spur wheel on it, which gears with an equal but broader spur wheel, L, on the controlling shaft, C, led from the bridge steering wheel, so that the screw, I, revolves turn for turn with the controlling wheel, D, at the bridge. It is obvious therefore that—the screw, I, being thus connected with the controlling shaft, C, from the bridge, and the nut with the barrel shaft—the actual movement of the screw longitudinally will not be governed by either of these independent of the other, but will be affected by both, and will correspond always to the difference between the motion of the controlling wheel and of the steering barrel, the screw being thus a differential apparatus. If the nut be held stationary while the screw, I, is turned, the latter will travel endways in the nut; but if at the same time the nut be made to revolve in the same direction, and at the same speed as the screw, there will be no end motion of the screw.

When the engine is at rest, the steam stop-valve, H, stands in its middle position, closing the cylinder ports entirely both to the steam and to the exhaust. If the controlling shaft, C, be now turned, the screw, I, being thereby also turned, will travel endways in its nut; and this end motion will be communicated by the lever to the stop-valve, H, which will thus be opened sufficiently to make the engine revolve in the direction corresponding to the revolution of the screw. The barrel shaft being driven by a pinion on the engine crank-shaft, S, will also revolve, and with it the nut, the rotation being in the same direction as that of the screw, I. As the screw will continue to travel endways until the nut and the screw both revolve at exactly the same speed, the stop-valve, H, will continue to open until the motion of the engine corresponds exactly with the motion of the controlling shaft, C, from the bridge,—that is, until the engine is moving at the speed required. This self-acting adjustment, which has taken some time to describe, is all done at the very moment that the bridge steering wheel is moved, in consequence of the automatic action of the differential screw; and the motion of the steering barrel at the stern is sensibly simultaneous with that of the wheel, D, at the bridge. The same action, of course, takes place on occasion of any change in the rate of motion, the position of the stop-valve being immediately altered to give the corresponding speed of engine; and when the motion of the steering wheel at the bridge is discontinued, the valve closes just so far as to maintain the engine at rest.

If there is a strain on the rudder in the position in which it is required to be held, the stop-valve does not shut altogether, but only so far as to maintain just such a

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pressure on the pistons as will exactly counterbalance the pressure on the rudder. In this condition the engine becomes simply an automatic steam break, requiring no attention from the steersman. If the strain alternates from one side of the rudder to the other, the stop-valve immediately reverses its position so as to bring the steam pressure on the opposite side of the pistons, and thus restores the equilibrium. However suddenly or violently this alternation of strain may take place, there is no danger to any of the men, as the differential screw is constantly ready for work, and its action is far more perfect and trustworthy than the labour of any number of men at the wheels. Manual labour indeed is not at all adapted for this kind of effort; for while the men are pushing the wheel in one direction it may suddenly happen that the resistance changes its direction, and the men are thrown over the wheels, partly by the force they themselves are exerting, which they cannot change quickly enough to the contrary direction. But in the steam steering gear the differential screw is a perfect automaton, changing the action of the valve not after the change of the strain on the rudder, but by that change itself and simultaneously with it.

The differential screw, I, has a free range of two turns, equal to $2\frac{1}{2}$ inches of longitudinal travel, supposing the nut were held stationary; and there is a stop clutch on each end of the screw limiting its travel. In the steam steering, however, the rudder follows so closely the movements of the steering wheel at the bridge, that in all ordinary weather the screw does not run more than one quarter of a turn in advance of the nut; in which case the steering wheels (if any) at the stern are one quarter of a turn behind the wheel at the bridge. Supposing the wheels to be then revolving at a speed equivalent to thirty or forty turns per minute, the steering wheel at the bridge will be about half a second in point of time before the wheels at the stern; and as the advance of the differential screw is less for a lower speed, the result will be about the same in respect of time,—namely, that the stern wheels or barrel will be only about half a second behind the bridge wheel, whether the latter is being turned rapidly or slowly.

The *Great Eastern* is fitted with a rudder indicator and steering dial at the stern, adapted to steering either by men alone or with the engine. This indicator is worked by the same steering wheel, D, at the bridge, and is indeed always working, whether steam-power or manual labour is employed; so that the engine can be thrown out of gear and men put to the stern wheels without making any change at the bridge, or without the steersman at the bridge being even aware that a change has been made.

Two toothed sectors, each turning independently on the same centre, are actuated by worms on shafts from the barrel and from the controlling shafting respectively.

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The worms working into the arcs are made with contrary threads, the one right-handed and the other left-handed, in order that by the movement of the two shafts in the same direction the two sectors may also be turned in the same direction. One toothed sector carries an index cast in one piece with it, and being actuated from the barrel shaft through the differential nut, it indicates upon a graduated fixed dial the actual position of the rudder, and is therefore called the rudder indicator. The movement of the other sector is directly controlled by the steering wheel, D, at the bridge; this sector also carries an index, called the director; but this index is jointed to both the sectors, and the distance between the centres of the two joints being short as compared with the length of the index, any difference in the motions of the two toothed sectors is shown magnified at the extremity of this jointed index arm, and the men at the stern steering wheels are thereby directed to put the wheels over to the side towards which this index points. This jointed index travels over a graduated scale formed on the arm of the rudder indicator, and by its position shews how much the wheel at the bridge is in advance of the steering barrel, and thus indicates that the steering wheels should be moved faster or slower in order to keep pace with the movement of the wheel at the bridge.

By this arrangement it will be seen that the differential movements of the screw, I, and its nut relatively to each other produce similar differential movements of the two index arms relatively to each other, the difference being magnified by the director upon the graduated scale formed on the rudder indicator. When the wheel at the bridge is moved in either direction, the director advances in the same direction beyond the centre of the rudder indicator, and remains in advance until the actual position of the rudder corresponds with the required position; as soon as this is the case, the bridge index, the director, and the rudder indicator, all point to the same position for the rudder.

In addition to this visible intimation to the steersman, there is also in the *Great Eastern* a bell with hammers fixed on the upper end of the differential screw. A pin is fixed in the nut so as to engage with the hammer levers, in order to give signals of warning, and if required, to strike repeatedly for urgency. The signals are, one stroke of the bell on leaving the centre in either direction, and one stroke when the required position is reached; and these signals are given by the ordinary movement of the steering wheel, without requiring any separate action for the purpose. Should the steering wheels be turned too far, the bell will strike again, and the director finger will point in the contrary direction; and it is the duty of the men at the wheels to maintain the director midway between the two strokes of the bell. In the actual working of the apparatus on the *Great Eastern*, the indicator and bell fulfilled their purpose admirably; but as the automatic steam steering also answered completely, these additional appliances were not really required, and unless for some special reason they would not be made again.

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The steering wheel, D, at the bridge, as well as the spare controlling wheel, Z, aft, is provided with stops corresponding to the two extreme positions of the rudder, by means of the traversing stop-nut, Q, working on a screw cut upon the shaft of the hand wheel, D. This nut is prevented from turning with the shaft by sliding along a fixed guide plate below, and carries projecting stops which catch at either end of its traverse against stop clutches fixed on the shaft, thereby preventing the further rotation of the shaft when the extreme position has been attained in either direction. The hand steering wheel, D, is itself connected to the shaft by means of a safety clutch at Y, formed of two pieces engaging with one another by inclined driving faces. The other half of the clutch, on which the hand wheel, D, is fixed, turns loose on the shaft, but without any end movement; while the after half, sliding by a feather on the shaft, is held up in gear by the spiral spring, R. The pressure of this spring is adjusted for holding the inclined driving faces of the clutch, Y, in gear, and thereby enabling the hand wheel, D, to turn the shaft, so long as the traversing stop-nut, Q, leaves the shaft free to turn; but when either of the stop clutches catches against the nut, Q, the safety clutch, Y, gives way under any force turning the hand wheel, D, further in the same direction, by the inclined driving faces of the clutch slipping past each other, forcing the clutch out of gear. This slipping of the safety clutch, Y, does not derange any of the pointers, and the clutch requires no throwing in again, as it comes into gear itself at each turn of the hand wheel, D; and the irregularity thus produced in the resistance of the hand wheel indicates at once to the steersman that the wheel is not driving the shafting. This form of safety clutch is preferable to the common friction clutch, which can never be regulated to a given pressure as this is; and to make a friction clutch slip requires at least as much force as before it slips, so that there is no direct intimation of the slipping.

The shafting, C, communicating from the hand wheel, D, at the bridge to the steering gear at the stern, is formed, for the sake of lightness, of drawn iron tubes, $1\frac{1}{4}$ inch external diameter and $\frac{1}{4}$ inch thick, turned down at the bearings to $1\frac{3}{16}$ inch diameter, and running-in bearings bored out to $1\frac{1}{4}$ inch diameter. The total length of this shafting is 410 feet in the *Great Eastern*, and there are about fifty pedestals to carry it, and five pairs of mitre wheels, in addition to the rest of the working gearing at the bridge and at the stern. The shafting had not been oiled from its erection in March, and in November it was still as easily worked as when first erected; the whole line of shafting can be turned easily even with the power of one finger at the bridge wheel, D. The fixing of the pedestals in the ship was very carefully performed, in order to ensure great accuracy in lining off the shafting; and to this in a great measure is the ease of working to be ascribed. The shafting lies in one of the box beams or tubes, formed in the upper deck, and is carried in a straight line through the interior of it; the twist upon the whole

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shafting, including the play in the teeth of the pinions, is about one-eighth of a turn. In one modification of this system of steering, the same operations are accomplished with a rope connection instead of the shafting; and in another arrangement the connection is made by water pipes, not transmitting steering power, but simply working the differential screw by water pressure: the shafting, however, is considered to be the best adapted to the work. This system of steering is peculiarly well adapted for ships of war, as the steering can be controlled from a protected look-out forwards, or from any other position in the ship, while the steering engine can be placed below the water-line.

In order to prevent accumulation of water in the cylinders of the steam engine when not in motion, the steam passages are formed to droop from the lowest part of the cylinders towards the exhaust. The steam pipe to the steering engine being 250 feet long in the *Great Eastern* from its connection with the main steam pipe, a self-acting steam trap is provided to allow the discharge of any water that may condense in the pipe. There are no escape cocks or escape valves on the engine, but not the slightest hesitation has ever been found in starting the engine after standing for any length of time without motion with steam on. This getting rid of all condensed water was made a first consideration in the arrangement; and the expedients adopted for the purpose have proved thoroughly satisfactory.

The engine shaft, S, has a disc crank on each end, and a pinion on this shaft drives a spur wheel on the barrel-shaft, the proportion of the gear being one to five. In the *Great Eastern* the number of turns of the barrel-shaft is seven either way from the 'midships position of the rudder, or fourteen altogether; so that to put the rudder over from 'midships to hard-a-port or hard-a-starboard requires thirty-five revolutions of the engine. The cylinders are 10 inches diameter and 12 inches stroke. The steam is supplied from the main boilers of the ship, and the size of the engine is sufficient for steering when the steam pressure is only 7 or 8 lbs. per square inch; but the pressure is intended usually to be 20 lbs.

The driving pinion on the engine shaft is fitted on feathers on the shaft, and can be slided out of gear, even while the engine is running, by means of a forked arm working upon a screwed shaft turned by a hand-wheel. In the case of the *Great Eastern* the steering engine was specially fitted to act as a steam windlass with two-grooved winding drums, in order to turn the engine to some account when not steering. For this purpose the driving pinion, when not in gear with the rudder-shaft, is in gear with two spur wheels on the shafts of the winding drums, the proportion of the gearing being one to four; and a hand starting lever on the valve shaft is then used for working the steam stop valve, H, instead of the differential gear. This winding gear was added to the steering engine at the request of Captain Anderson, but it is

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omitted in the drawings as not forming part of the steering action. The details of the engine itself are so simple and durable that there is little chance of its getting out of order. All the parts are made of extra strength, and the wear of any of them will not prevent the working of the engine.

The last voyage of the *Great Eastern* to New York was a very stormy one, and afforded an excellent opportunity for trying the efficiency of the steam steering engine. Originally Captain Anderson intended not to use the engine for steering except when out at sea, considering that the ship could not be safely trusted to any steam steering engine when within sight of land; but when the apparatus was completed and its sufficiency became more apparent, the steering of the ship from her moorings in the Mersey was committed to the engine, although the precaution was taken of having men standing by ready to take the wheels if needed. The action was from the first quite satisfactory, and as the mode of steering is just the same as steering by hand, no time was required for training the men to work it.

When approaching Cape Race at the end of the voyage, the sea being very rough, the men were ordered to take the wheels and the steam engine was disconnected. This was done, not because there was any defect in the steam steering, but because a storm was coming on and the vessel was on a dangerous coast, and there had been no experience of the steam steering in a storm. The men had been however only about a quarter of an hour at the wheels, when it was evident the vessel was not steered so well as before, and the men were already quite exhausted. The steam steering engine was therefore again connected, and it was used all through the storm, which was so severe that it necessitated turning the ship about for some time, after the forward bulwarks had been carried away, killing one man and injuring others. Turning so large a ship as the *Great Eastern* in such a sea would have been almost impossible with steering by hand; but it made no difference to the steam steering engine, and even when the ship got into the trough of the sea the wheel at the bridge was quite passive in the hand of the steersman, and could be moved as easily as in a calm.

The result was so satisfactory that Captain Anderson wrote from New York—"The steam steering gear seems perfection." The experience of its working on the return voyage was equally satisfactory, and Captain Anderson has expressed his high opinion of its value, especially for large steamers.

With reference to the application of this steering engine to H.M.S. *Northumberland*, Captain Inglefield has given such ample testimony to its efficiency, in the preceding Paper, that it only remains for the writer to thank him for his kindness in thus acknowledging the merits of a rival system.

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The general arrangement is not the best that could have been adopted, but is the best under the circumstances; the vessel being almost completed before it was decided to adopt this system of steering. It had therefore to be planned to be throughout an addition to the already existing means of steering. The steering barrel in connection with the engine is appropriated exclusively to the steam steering. The lower tiller has not been added on account of the steam steering; it was the spare tiller, or the fighting tiller, and can now be used either for steering by ropes led from the lower manual labour barrels, or by ropes led from the barrel at the engine.

In H.M.S. *Monarch* the arrangement is nearer to that adopted in the *Great Eastern;* the same barrel is used, and the same ropes for steam steering and for steering by manual labour.

In both vessels there is a wheel in the conning tower as well as on the quarter deck, and in the *Monarch* there is a third controlling wheel, on the lower deck, at the engine. The steering can be accomplished by a man at either of these wheels; they are all in gear at the same time, and either wheel can, at the will of the commander, be made for the time the master wheel.

The writer would here state that although men can assist the steam power, he does not recommend men and steam to be ever used at the same time, at the same work; it is a practice always attended with great danger.

This Paper refers to a steering engine only; not to the steering gear. It has, as yet, been applied only to steering barrel gear; but it is equally applicable to any known means of operating upon a rudder.

The steering engine has been worked only by steam; it will work as well by water. All the advantages peculiar to it may be retained if applied as a water engine. The model now exhibited has always been worked with water instead of steam. The question of the adoption of water or steam is one of convenience only, and the only alteration that would be necessary, would be to add another pair of wheels to increase the travel of the pistons. It does not however appear to the writer, that water would ever be found to be so convenient, especially if used at so low a pressure as is now proposed by Captain Inglefield. The force required to operate upon the rudder of such a vessel as the *Northumberland* is correctly given as 35 tons; describing an arc with a chord 5 feet in moving from hard over to hard over. This gives us 175 foot-tons as the mechanical work to be done, or 67½ foot-tons to put the rudder from 'midships to hard over either way.

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Now the available pressure from the external water, is that of a head of about 20 feet; or, a ton of water admitted is equivalent to 15½ foot-tons of mechanical work, neglecting friction.

To put the helm once over would therefore require the admission of five tons of water, and if we add for the power lost by friction, this quantity must be considerably increased.

This system of steering is also well suited for our mercantile steam ships; there the proposal to run some tons of water into the bilges every time the rudder was put hard over, could never be adopted. Messrs. George Forrester & Co., of Liverpool, who have introduced this system of steering, are now fitting it in the City of Brooklyn, a vessel being built for the Inman Transatlantic line of steamers.

DISCUSSION.

Mr. MAC FARLANE GRAY: Captain Inglefield's cylinder is 3 feet diameter, and the piston travels 5 feet. The area of a piston 3 feet diameter is 7 square feet, and the available pressure will be—say, half a ton per square foot—$7 \times \frac{1}{2} \times 5 = 17\frac{1}{2}$ foot-tons. A 20-feet head is, theoretically, 1,280 pounds. Captain Inglefield also tells us that, as to the rudder, the pressure required is 35 tons, at a distance from the tiller such that it is required to move 5 feet. It therefore stands in this way:—

35 tons
5 feet
Work to be done, 175 foot-tons.

And that is to be done by 17½ foot-tons. In the *Northumberland*, I have 182 foot-tons. Supposing we have 20 pounds pressure: that is the power available to put the helm from hard a-port to hard a-starboard. If Captain Inglefield will do this with 17½ foot-tons, I will make him a present of all the friction, and admit that he is right. I have the model here, which has been made to work as a steam engine, or by water pressure. There is no water pressure in this building, but I have borrowed a fire engine for the purpose of working it here. The model shews it exactly as it was in the *Great Eastern*, *minus* the telegraph part, which has been removed from the model. The one wheel goes exactly the same as the other—in fact, they correspond. It can be made to go as slowly as required, and the speed of the one increases exactly as you increase the speed of the other. If you want it to go one way, it will go just as you move the wheel. If you wish it to go the other way, you have only to reverse it. In the *Great Eastern* the one went the same as the other. Mr. Barnaby, who saw it, can speak with reference to it. You could not get a difference of more than a quarter of a turn.

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Captain E. A. INGLEFIELD, R.N., F.R.S.:* How many revolutions does the small wheel make, to put the helm from hard a-starboard to hard a-port?

Mr. MAC FARLANE GRAY: Thirteen in the *Great Eastern*, nine in the *Northumberland*. It goes, a wheel for a wheel. It will go just as you require it. If I turn the one, the other follows it exactly.

Mr. E. A. COWPER: Have you no provision for retaining the heat in the cylinders?

Mr. MAC FARLANE GRAY: It is all right when once the steam is put in: the cylinders are only felted.

Captain INGLEFIELD: Is not the steam liable to become condensed when the tiller is for a long time at rest, as it sometimes is in a long voyage?

Mr. MAC FARLANE GRAY: If you once start it, and keep the steam in, it never stands while the steam is in. In the *Great Eastern* the engine stood on the upper deck unprotected. There was no difficulty anticipated from water collecting in the cylinders, and there was none experienced.

Captain INGLEFIELD: But is not the steam liable to condense in the cylinders; and should there not be a blow-off pipe to admit of the condensed water escaping?

Mr. MAC FARLANE GRAY: We provide for that,—in the first place, by arranging the pipes so that no water will be carried into the cylinders, and then by making the cylinders so that no water will lie in them. We have neither drain cocks nor escape valves—we were so confident in the sufficiency of the other arrangements.

Mr. JOHN SCOTT RUSSELL, F.R.S.: If the small pipe that brings in the steam is so sloped that everything must return from it, the water will not lie. I presume that that is what is done.

Mr. MAC FARLANE GRAY: Precisely; and after the steam is once in at the beginning of the voyage, it is all right.

Captain INGLEFIELD: Have you a special boiler for this apparatus?

Mr. MAC FARLANE GRAY: No; we have the ordinary steam boiler.

Mr. COWPER: If it stands for ten minutes, or a quarter of an hour, how do you get rid of the water?

Mr. MAC FARLANE GRAY: There is a slight leak—it runs from the lowest part of the valve. Mr. Kelson can tell you that he has had no difficulty in setting it to work after it has been standing.

Mr. KELSON: I have started it, after it has been standing for three hours, without the slightest trouble.

Mr. MAC FARLANE GRAY: During the trial of the *Northumberland* I may state that Captain Willis and Captain Roderick Dew were on board. I asked them before the trial finished if they would not go to the conning tower and see how it worked. Captain Dew ordered a man to go to the wheel. I suggested to Captain Dew whether he would not like to work it himself? He said he would. He put

* Now Rear-Admiral Inglefield, C.B.

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the wheel hard over and held it. I told him he might now leave hold. He had not realised that the wheel could be left to itself in any position. I explained that to him, and he left the wheel and looked over the side to see that the vessel was actually under helm hard-over. He then walked before the wheel, saying, "Look at that!—look at that! I will always steer my vessel myself in any difficult channel." It was then proposed to make further trial of steering by hand for the purpose of "comparison." Captain Dew was so satisfied of the superiority of the steam steering that he seized upon this word, and said, "Comparisons are said to be odious; but, in this case, it will be perfectly ridiculous. There can be no "comparison—no comparison! They should not be named in the same sentence together." The *Northumberland* was all this time making circles, with no one at any of the steering wheels. Captain Dew was himself the steersman, and yet he was walking about. Captain Willis was also highly satisfied with that trial. It took 19 seconds to put the helm hard over in the *Northumberland*. By the use of the apparatus, you have perfect control—far more control than you could obtain by the employment of any number of sailors. You can do whatever you like with it. If you were to put a thousand men on to steer, the mechanism would do more than the thousand men, or any other number.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): Now that we have heard the explanation of Mr. Gray, if any gentleman will be kind enough to make any observations upon this Paper, we shall be glad to hear them. Perhaps Mr. Scott Russell, as you are the father of the *Great Eastern*, you will let us have the benefit of your knowledge and experience.

Mr. SCOTT RUSSELL: I can only return my best thanks to Mr. Gray for the very kind attentions he has paid to the welfare of my child. I am very grateful to him. I must say that I think his method of rendering steam-power as handy as a telegraph from a great distance is extremely meritorious, and to my mind it has the additional merit of being incredibly simple. I think I am right in apprehending that he keeps his engine always in a state ready for work. I confess I have really nothing to say upon it, because it seems to me to be so clever and so good.

Mr. COWPER: I should like to make one or two observations with reference to the steering apparatus. This subject was discussed two years ago at the Institution of Mechanical Engineers, and a great deal of experience was brought to bear upon it. But I think the whole question of steering a large rudder for a large ship must be looked at with reference to this machine, as with reference to any other. You require at a moment's notice to put into operation a large power—say the power of forty men,—very quickly and very suddenly, first in one direction, and then in another; therefore you must not trust any machine that will take two or three minutes to get ready. I think there is a great chance of condensation in the cylinders when you use steam, but that might be avoided by a steam jacketing, which of course they ought to have, because there is then no fear of the cylinders getting burdened with water. If there were water there, and the rudder had not been moved for some time, there would be some difficulty in the first few strokes; but I believe they are kept warm, in most instances, by a constant dribble through the cylinders, which has the effect of keeping them warm. I understand that there is no special boiler required, but that the ordinary boiler is used. Then taking this in comparison with any other power which can be applied very suddenly, it becomes a question, which is the most convenient of the two? I must say that Captain Inglefield's strikes me as a simpler plan than that of Mr. Gray which we have now before us. Although this is a very good machine, I think Captain Inglefield's is better, because you do not require always to have the steam up, or to have the steam at a

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certain pressure. If you take water into the ship, as you must do day by day for the purpose of cleaning, you may as well get power by that water which is so taken in. There is no complication, or addition to the ship, with the exception of the pump at the bottom, which makes several 5-feet strokes, and pumps the water at a higher pressure. The power is not limited, as seemed to be assumed by Mr. Gray. The pumps of Captain Inglefield make as many strokes as necessary. There is a large area of piston, against which the pressure is exerted, and the pumps make as many strokes as are requisite. There was some misapprehension in the discussion, and I was not aware that Captain Inglefield had been called upon to reply, or I should have made this explanation before.

Mr. MAC FARLANE GRAY: How many strokes are made?

Mr. COWPER: From hard a-starboard to hard a-port there would be three or four.

Captain INGLEFIELD: When a seaman at the common wheel is ordered to right the helm, he lets go, and it flies round in the ordinary manner. The action of the passing column of water on the surface of the rudder causes the helm in my plan to right itself. I do not require the engines at all.

Mr. COWPER: It is done with the greatest freedom, and the greatest nicety; and I am bound to say that it is also done with great freedom and nicety by the other apparatus. You have merely to direct the water one way or the other, and you get what you require. But in the one case you have to depend upon there being a sufficiency of steam, while in the other case, there is the column of water always ready and available for power, due to the depth of the ship. I confess I think that appliances of that character and nature will best effect the object of moving the rudder of a ship over, quickly and readily, and are very much better than any other complication, such as hydraulic-pressure cylinders, and so on.

Mr. A. BOWER: It seems to me, with regard to the difference which exists between the two plans that have been suggested, this observation may fairly be made. If you were to send an able-bodied seaman, who knew nothing about Captain Inglefield's plan, to steer the ship, he would not be able to do it; but if the plan adopted on board the *Great Eastern* and the *Northumberland*, were adopted in any other vessel, and an able seaman were sent to steer, he would be enabled to do so, because he would know that as he went two spokes, or three spokes, and so on, so the helm followed. The peculiarity of Captain Inglefield's apparatus is, that he only goes three-fourths of a circle, and you could not send any ordinary man to the wheel, for the purpose of steering, for he would not understand it. Of course that has nothing to do with the relative merits of the systems, but only has reference to the relative readiness with which a man could steer without being specially educated for it. Captain Inglefield has a large amount of resistance on the rudder. In Mr. Gray's machine, there is always the full power on, but it cannot move, except at the rate at which the man at the wheel turns his small steering wheel, and the moment he stops the one, the other must stop likewise. Captain Inglefield locks the water dead in both passages, so to speak, so that he has a rigid body to hold the rudder in whatever position it is put. But if a heavy sea strikes it, what is the consequence? We all know that if there is not some yielding body, something must break. Something must yield, unless indeed everything is made so strong as to resist the most powerful blow that the sea can inflict. If a heavy sea (such a sea as would break anything of that rigid character) strikes the rudder, the result is that it either breaks it, or bursts the cylinders in Captain Inglefield's apparatus. Whereas, if such a sea strikes the rudder in Mr. Gray's apparatus,

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the rudder is driven over for a moment without the man at the wheel knowing anything whatever about it. But the engine would then go to work, and bring the rudder back again to the very position from which it was forced by the sea. Captain Inglefield does not obtain these points, which are irrespective of the question of power. The speed at which the power is used in Mr. Gray's apparatus is entirely under the man's control at the wheel, without the man who is steering knowing anything about it; as by this plan of Mr. Gray, if he goes quickly it is answered quickly, and if he goes slowly, the helm goes slowly also. These are the marked features of difference in the two plans, and I think they are more questions of trial and proof as to their respective merits than anything else. I believe Captain Inglefield's will soon be at work, and then we shall be able to judge of the difference. There are undoubtedly great merits attaching to Captain Inglefield's plan, which, I should mention by the way, possesses great similarity to an apparatus that has been already fitted—a hydraulic steering gear, where they have two cylinders, but no pumps. It is in fact using, at one moment, power which is stored up, and then forced into the sea again.

Captain INGLEFIELD: I will first say a word with regard to the question of the difference between my method and the ordinary one being so great, that if an ordinary steersman were sent to the wheel he would not be able to perform his duty efficiently. I have so arranged the system that an ordinary able seaman can go to the wheel, and steer just the same as he would with the ordinary steering apparatus; only, instead of going four or five spokes or the whole circumference, he would go three-fourths, and a diagram or dial-plate is put before him, shewing the exact position of the helm, which prevents the possibility of misunderstanding or mistake. When the rudder is brought to the proper position, by means of the slide, he locks the water in the two cylinders, and the rudder remains. He may do also what was mentioned by Mr. Gray; that is, he may walk away from the wheel and leave it, and the rudder will be perfectly secure, either continuing to go down or locked in any given position as desired. Again, the ship can be steered from the lower deck or screw alley, which is an advantage. Something was said with reference to a heavy sea striking the vessel, and its being necessary for the rudder to yield. That is a point I have not lost sight of. I propose to fit a relief valve which would, in the event of any very heavy blow of the sea, admit of the escape of the water from one tiller cylinder to another, thus putting them for a moment in equilibrium. With regard to the quantity of water that may be admitted in a ship, and its uses, we all of us know that it is customary, in men of war, to admit a certain quantity of water in the ship's bilge for the purpose of keeping her clean, it being afterwards pumped out by hand. The quantity of water required for my apparatus on ordinary occasions of steering would be under the quantity of water that is usually pumped in for the purpose of cleansing the vessel. In the *Prince Consort*, it was the duty of the engineer to pump in a certain quantity of water, which was afterwards pumped out by hand, and that process was continued until the water pumped out was bright and clear, which was the test of the ship being clean. The apparatus, therefore, can be used either steaming or sailing. A balanced rudder has been often quoted on account of its easy management as needing no such apparatus for steering purposes, but I would suggest that my arrangement is constructed so as to place the steering gear comparatively out of danger, and, with an easily managed rudder, the engine might be very materially reduced in dimensions; while, like all water engines, it requires much less attention than a steam engine. In a steam engine, it is necessary that the packing should be looked to, and various other things done, which are not requisite in the case of a water engine. I had an opportunity of seeing a water engine which had been put up by Sir William Armstrong,

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and had been at work for twenty years; and the engineer told me that during those twenty years, it had cost only £5 for repairs.

The CHAIRMAN: I think these two Papers upon Steering Apparatus ought to have been read before any discussion took place, so that they might have been discussed together; and I should propose now, in thanking Mr. Gray, that we should thank Mr. Gray and Captain Inglefield conjointly for having given us important information upon this subject.

[The thanks of the Meeting were voted by acclamation.]

Mr. CHARLES F. HENWOOD: Before this Meeting is adjourned, desire to I give notice of two Resolutions which I propose to bring forward to-morrow. It may be for the convenience of the Members that I should mention them to-day, in order that they may consider them. The first is with reference to the title of this Institution. Upon that subject I shall move, "That in the opinion of the Meetings "considering the Resolution agreed to on Thursday last to admit Marine Engineers as Members of the "Institution, the Institution henceforth should be styled, 'The Institution of Naval Architects and "'Marine Engineers.'" The second Resolution is this:—"That in the opinion of the Meeting, the "objects and interests of this Institution would be greatly advanced by more frequent Meetings, and by "the publication of the *Transactions* in a less expensive form, and in monthly parts." I would merely add that I propose these Resolutions in no unfriendly spirit, but, on the contrary, am solely prompted by the desire to make this Institution more useful and interesting than it has hitherto been.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): If you will be good enough to hand in your Resolutions, in writing, they will be laid before the Council, and receive its best attention.

Mr. JOHN SCOTT RUSSELL, F.R.S.: I think it would be a more regular proceeding, if the Mover, Mr. Henwood, would forward these Resolutions to the Council. I may state that the Council is already occupied with the consideration of those points, and there is a Special Meeting to be called hereafter, when it will take up those subjects and consider them. I would suggest that the best way would be to let the Council have these Resolutions.

Mr. C. F. HENWOOD: Then the subject would hardly come before the Members, which I am anxious it should.

Mr. SCOTT RUSSELL: Not at this Meeting.

Mr. C. F. HENWOOD: Naval architects are now placed in rather an anomalous position. For you do not call naval architects, marine engineers,—yet you call marine engineers, naval architects.

Mr. SCOTT RUSSELL: All that has been most anxiously thought of by the Council.

Mr. C. F. HENWOOD: My intention is to bring the matter before the whole Meeting to-morrow, at the conclusion of the reading of the Papers.

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The HONORARY SECRETARY: I would suggest to Mr. Henwood whether his object will not be sufficiently served by his having mentioned the subject to-day, the Council meeting in April and taking it into consideration as it will do, and also giving in his Resolutions. The only time at which it could be brought forward to-morrow would be just at the close of our General Meeting. Two things will then occur. In the first place, the Meeting will not have had full time to consider the matter; and secondly, there is generally a very scanty attendance at the close of the proceedings on Saturday. Consequently, I do not think, if it were brought forward formally now, that it could receive that careful consideration which is demanded by such an essential point as the change of name of the Institution; and I should think it my duty to meet such a motion with an amendment for delay, which would practically tend to throw the matter over until next session. It will be discussed carefully at the Council Meeting which is fixed for the 14th April; and if the Council then, on careful consideration, thinks it right to recommend to the Meeting a change of name, that will be brought forward in the proper and regular way at the next General Meeting of the Institution.

Mr. C. F. HENWOOD: The Institution has already changed its character; and I think we ought not to run on for another year without its name being changed. I do not think it is right to alter the character of the Institution without at the same time altering the name.

The CHAIRMAN: It should be observed that the question at issue involves a great number of things besides the simple change of name, which is not merely a verbal change, because we must deface our seal, and construct a new one. There are various other subjects which will have to be taken into consideration by the Council. If we alter the name, the seal must be entirely altered to suit the new name of the Institution. Until the Council has fairly considered the matter, I do not think that the whole body of Members, as represented by the few that are here to-day, would be disposed to enter into such a discussion. If Mr. Henwood will send his Resolutions to the Council (and I can assure him that precisely what he has suggested has been moved in the Council) they will receive that attention to which they are entitled.

The HONORARY SECRETARY: I desire to add that I have not spoken in the name of the Council at all, but merely wished to point out that, practically, inconvenience would arise if these Resolutions were brought forward on the present occasion, especially seeing that two or three Members of Council only are present.

Mr. C. F. HENWOOD: I am obliged for the suggestion; but I wish to give notice that they will be moved to-morrow.

The CHAIRMAN: The notice will be duly recorded.

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ON THE QUALITIES OF BOILER PLATE.*

By S. M. Saxby, Esq., R.N., Associate.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; Vice-Admiral Sir Edward Belcher, K.C.B., Vice-President, in the Chair.]

At the Meeting of this Institution, in 1868, I opened the question of testing iron by magnetism.

Results of a great number of experiments on bar and forged iron were then referred to, and a general (perhaps vague) belief was established that something might possibly be done by means of magnetism, much to the advantage of both manufacturer and consumer, to assist in the better examination into the quality of iron.

Encouragement from Members of this Institution to proceed, was, I may say, almost unanimous. If an adverse doubt escaped the lips of one or two persons, it was from those who had the honesty to confess but a small acquaintance with the general principles of magnetism.

I think I shall be acting in accordance with the wishes of those present, if I touch briefly upon some subsequent experiences as regards wrought iron,—before I proceed to state recent discoveries as to the testing of rolled plate iron. In these I will confine myself to such of my work as was performed under the eyes of Government officers.

Those who were at the Meeting of April last, will probably remember the earnest manner in which the gallant Admiral who presided (and also some others) expressed a hope to hear the subject renewed by me at this opportunity; but I must ask your indulgence, as for one who is attempting to walk on ground hitherto, I believe, untrodden.

In resuming the subject, I need not revert to the principles on which it is sought to establish a system of testing iron by magnetism; these are published in the Transactions of this Institution.

* Received 18th February, 1869.

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I would recal to your remembrance that I briefly described an early, but successful, attempt to test small arms and heavy guns at Sheerness; and now proceed to follow up what was then said, with a few remarks upon further and decisive experiments therein.

The Secretary of State for War kindly permitted me to make some experiments at the Enfield Small Arms Factory, it being beforehand understood that reimbursement of personal expenses was to be contingent on success alone. It is some proof of progress to be able to say that my expenses *were* allowed and paid.

Of course no difficulty occurred at Enfield in the testing of such articles as swords, bayonets, foils, gun springs, ram rods and so on: for all these I found magnetism to be an unquestionable and all powerful test. That it was equally so with gun-barrels the following will shew—I need only give one example:—

It was thought by Colonel Dixon, the superintendent, desirable to carefully test one selected barrel in each state of its manufacture:—and accordingly

1.—We first tried it with the magnetic test *in the state in which it came from the fire.*

2.—We next tried it *after it had been turned up in the lathe.*

3.—And then again *after it had been ground and carefully bored.* (I have reason for saying here that at my request a temporary wooden frame was made in which the barrel could be easily revolved; and it greatly facilitated testing).

The result was that throughout each of these stages, I detected an imperfection not far from the muzzle, and extending for some inches down the barrel; but I declared the fault to be not of sufficient importance to condemn the barrel; but Colonel Dixon was (I think, very consistently), resolved to ascertain, once for all, the value to be attached to magnetic indications; even were it necessary in so doing to cut up the barrel. This became necessary, and a piece about $2\frac{1}{2}$ inches long was first cut off the muzzle end.

The section itself exhibited no fault to the eye; but the new muzzle end retained its power of disturbing my needles; and I still with confidence declared that, for several inches downwards, unsoundness existed, but that beyond this the barrel was of iron of very great purity and in perfect condition.

Colonel Dixon next heavily tested the barrel with gunpowder; it bore the explosion without exhibiting any fracture; but my magnets (under his immediate observation) still gave signs of the declared unsoundness.

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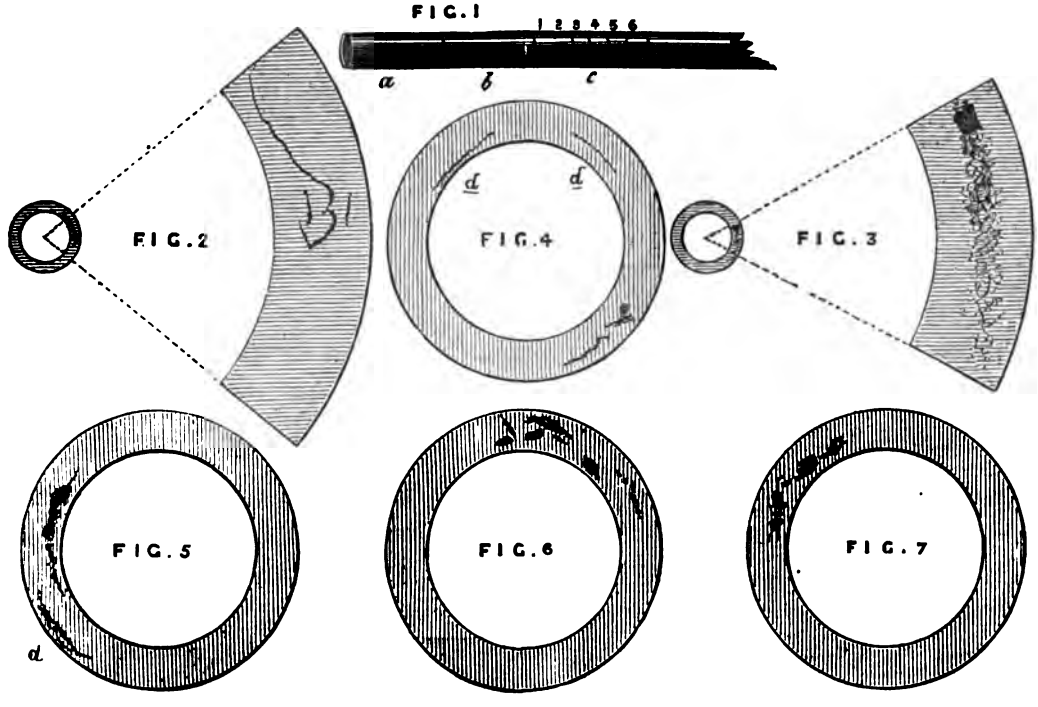
The barrel was again heavily charged with gunpowder, and plugged at the muzzle with loam for about 2 inches, in order to blow off the muzzle-end. In the piece thus blown off, nothing faulty presented itself; and yet, on re-applying the test to the second new muzzle-end, we found the same indication of defective condition of the metal for some inches.

As a last resource, this second muzzle-end was cut up into six ½-inch cylinders; when the result proved the perfect accuracy and infallibility of my system of magnetic testing; even in its then partially developed state.

Fig. 1 represents the barrel tested: *a* is the part cut off; *b*, the part blown off by gunpowder; *c*, the part cut up into ½-inch cylinders.



Figs. 2 to 7 are intended to represent the appearance of the different cylinders. In Fig. 2 the flaw consists of a crack filled with cindery slag; in Fig. 3 there is cinder and a kind of unsoundness, called "spongy iron;" Fig. 4 shews flaws and "grays;" in Fig. 5 we have grains of sand and a "gray;" in Fig. 6, cinder; and in Fig. 7, grains of sand.

It is only at this moment necessary to mention that in one is seen a condition of iron, to which various names are given by smiths, such as "fired," "spongy," &c.;

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but it is very remarkable that this seems to be a condition to which even the best iron is liable; and manufacturers, on seeing the sample, will, at once, understand what I mean.

I shall, presently, have occasion to illustrate this, when speaking of boiler plate; and, from what I have to shew you, it will appear to be a fault of manufacture. Whether this be unavoidable, I cannot say; it is enough for me to declare that it is detectable by magnetism.

Now, on a cursory examination of the defects in the other small cylinders of the barrel, it was at first supposed that the heavy explosive strains, to which the barrels had been subjected, had produced them; but on a careful examination under a microscope, I plainly detected in the crevices of these flaws, not only cinder or slag, but distinct intermixtures of sand with the metal; these constitute what at the Factory are called "grays" (see *d*, Fig. 4). If these are visible to the eye at either the outer or inner surface of the barrel, the article is at once condemned; but those in the cylinders were concealed within the substance of the metal, and magnetism shewed their presence.

Of course this extreme delicacy of testing is not called for in general commerce, and the use of what I propose to call a "parastatic" arrangement could alone have been so successful; but it was Colonel Dixon's object to ascertain, as a scientific question, the full extent of the reliance to be placed on the accuracy of magnetism, as applied in this direction, and he succeeded. I mention this because the thorough examination of its use in one direction will assist in clearing the way for a more satisfactory examination when we apply it to rolled plate.

But now it much concerns iron shipbuilders and iron manufacturers, to know, after all this, the reason why my method has not yet been adopted at the Enfield Factory; not to explain this, would lead to the impression that I had failed in proving what has been advanced as to its usefulness.

The true state of the case can best be gathered from reading the reply of the Secretary of State for War (as communicated to me officially through the Assistant Director of Ordnance). He says:—"No practical benefit is, at present, likely to be "derived by the adoption of your system in connection with the manufacturing "departments at Woolwich and Enfield, he" (the Secretary) "therefore regrets that he "cannot comply with the request, that a wooden lathe might be fitted up in the Royal "Gun Factory for your use. He considers, however, that the experiments conducted by "you at Enfield, were of a sufficiently interesting nature to justify him in paying the "expenses," &c.

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This requires some explanation:—

I am as anxious as any one can be that the public should not in any way, or on either side, be misled through misconception as to magnetic testing.

1.—As regards Enfield:—After having spent about a fortnight there, and having seen, with a not unpractised eye, the whole details of their manufacture, I am bound to acknowledge that I never saw anything to equal the care and precautions and economy with which the work is there conducted; and nothing can surpass the excellence of the material used; so the real fact is, that under Colonel Dixon's superintendence (if he will forgive my presuming to offer an opinion), there is no room for improvement.

I carefully, in the presence of him and Captain Eden, R.A., and the Manager, examined more than fifty gun-barrels—some of steel—some of iron; and declare that a very large proportion of them were (even under the powers of the parastatic needles), absolutely faultless:—what *more* could be said of any branch of manufacture at the present day? What more *can be wanted* at Enfield?

2.—But now, as regards my *single hour's* work at Woolwich Arsenal (for that is about the extent of my experience there) it is but just towards the War Department, to say that I went to the Arsenal with full permission to examine heavy ordnance, as given in the following official words:—"The Superintendent of the Royal Gun Factories has been "instructed to afford you the necessary facilities . . . . . for the purpose of "applying your magnetic test to a steel tube." But there was some mistake; for while I received every possible assistance in the Arsenal, there was one obstacle that neutralized everything. I had the mortification to find that, from the want of a special order from the War Department for the Colonel-Superintendent to incur expense in labour, to place cylinders favourably in position for facilitating examination by magnetism (many of the steel ingots for 20-ton guns being 11 feet long, and 15 inches diameter), my intended examination was stopped, unless I was prepared to pay all expenses; so that I could only try the two or three small cylinders lying, as they were, on the ground, or in the lathes, where I found the local attraction from the heavy masses of the various portions of the ponderous machines so inconvenient for testing, that Colonel Campbell kindly advised my applying to the War Department, to allow for a temporary frame of wood being roughly put together for my use, so that I might revolve a cylinder or ingot therein, for the purpose of examination, as I had done the gun-barrels at Enfield. I have already read their refusal.

Therefore, *in reality*, the assumed absence of any "practical benefit likely to be "derived" by the War Department (at Woolwich) from my system, is *totally irrespective*

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of its merits or capabilities: no one but myself knows them, or seems likely to know them. Government, with the best intentions, have virtually—by an omission on their part—declined to look at it in possibly one of its most important applications, without *any trial of its value!* (*N.B.*—The French are awaiting the result of my labours, and I am told would receive a communication from me with a welcome.)

In your inquiry as to what is likely to be the *use* of magnetic testing to iron ship builders and boiler plate makers, (for after all that is what we are all aiming at) one circumstance is worth your consideration; and I mention it to shew that the farther we *do* go into the subject the more satisfactory and promising it becomes. It is this:—When I was at the Arsenal, there happened to be in one lathe a steel 9-pounder for 3-inch bore: it had been hardened in oil. I did not let the presence of so much local magnetism as I saw about me prevent my making the best of my opportunity while on the spot.

After a rough mental estimation of the allowance to be made for such a drawback, I examined this cylinder while revolving, and in a few seconds was induced to place a chalk mark round a part of the cylinder, at which my magnets were strongly affected; I said to the chief foreman that the mass of metal on the left of the mark was decidedly different in condition from that on the right:—(*I did not then even know whether the metal was a gun or a mere ingot ready for boring*). On repeating the test with the same results, the foreman snatched up a small long rod, and *felt* the interior of the mass, and on measuring, found to his evident surprise that my chalk mark was precisely *over the chamber end* of the *partially bored* cylinder of the gun; again for ever deciding the question of magnetism being dispersed *throughout the mass*, and not merely, as some still suppose it to be spread near its surface; and no better proof of accuracy of any method can be desired by unprejudiced men.

I tested a second partially bored gun with the same conclusive result.

Now I would ask, Sir, whether I am wasting the valuable time of this Institution in endeavouring to apply these experiences to a wider range of usefulness, by attempting to furnish you with what you all crave for, *viz.*, a better means of testing iron in general, or in particular a more accurate means of testing rolled plate?

I am sure, Sir, that many who are present sympathize in my disappointment and discouragement at not having been permitted to continue these interesting investigations at Woolwich, except at my own expense; and the more so, when reminded that the testing of a large gun at present costs from £1,000 to £2,000—perhaps more;—while the magnetic test, if such a thing be found as practicable as it is accurate, will cost only as many half-farthings, and perhaps occupy only about $\frac{1}{100}$th part of the time, and $\frac{1}{1,000}$th of the labour.

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I now turn to the more immediate subject of my Paper, and beg your attention to a few remarks on rolled plate iron.

At our last Annual Meeting, I had not accomplished the testing of plate iron. That my first attempt had been a failure, was, perhaps, rather zealously impressed upon you; but you will probably recollect that, while on my part I acknowledged the failure of a mere inexperienced first attempt, I made some hopeful mention of a certain difficulty which had presented itself to me when making the first practical application at Chatham. I spoke of this "difficulty," as, what I then conceived to be, a power of dispersion possessed by terrestrial magnetism when traversing layers of iron of different qualities and densities. I compared this power to an analogous property possessed by light.

I have now the pleasure of announcing that, following up my then crude suspicions, I have satisfied *myself* (and before the close of this Paper I hope to satisfy all who hear me) that not only such a property in magnetism *does* seem to exist; but that by means of it we have a singularly elegant and simple, accurate and infallible means of testing rolled plate iron, for quality and soundness.

I do not assert that all has been accomplished that is possible to be done by this agency; nor that all has been done which, perhaps, manufacturers and purchasers may desire; for the scale on which I have worked has of necessity been limited. But I remember having recently, at a lecture, illustrated galvanic action in a boiler, by means of a common iron sewing thimble and a small brad—the one representing the boiler, and the other one of its stays—and no one who witnessed it considered the smallness of the scale as insufficient for the illustration of those principles, which a larger scale of operation could only have rendered more plainly visible. Now, my discovery may be considered to have reached this "thimble" stage—only requiring more metal, more space, and larger appliances to finally adapt it to practical purposes.

Already, I am safe in saying that something can be done *with* my magnetic testing, which no man living can do without it; and this is now about to be proved to you.

Dozens of small plates of different thicknesses have recently been tested with unvaried success, and under the observation of men, to whose judgment no one present would for a moment object. Some of these successes may possibly be perplexing to certain manufacturing firms; but if I mistake not, every manufacturer of rolled plate will prefer having a command over the *quality* of his material, to the present unmistakable uncertainty. Improvement in the *quality* of plate iron will assuredly increase side by side with the increased adoption of a better means of testing.

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We all know the progress which has been effected in this direction through the introduction of the Admiralty test for iron within these four years; and yet, who will say that something more is not loudly called for?

Iron ships founder,—cranks and shafts break,—whole crews miserably perish; and yet, still, not one workman in a thousand knows the *condition* of the metal he works. Quantities of plate are rejected,—manufacturers and purchasers alike suffer;—indeed there is much that is being anxiously watched by all parties; and only because there needs some more definite, searching, more complete means of testing rolled plate iron and steel.

I have called your attention to the Enfield works;—and ask why should the quality of iron used, for instance, at Enfield be exceptionally *good*, while the iron which is still put into our shipping, both naval and mercantile, is, as a rule, exceptionally and notoriously bad?

I am sure, then, that one or two facts which bear closely upon this subject, and which illustrate what I firmly believe is a remedy, will be acceptable to the Members of this distinguished Institution,—and I offer them with all deference; but if I cannot just now consistently make public all I know in this matter, the following will suffice.

Few men have so deeply investigated the powers of magnetism as the late Dr. Scoresby. Having no notion of the means of applying magnetism as a test of the quality of iron and steel, he believed in the possibility of doing it. And again, Captain Evans, of the Admiralty, not only believes in it, but in a limited way, and for a special purpose, has actually used the effect produced by the plates of a ship's iron on his magnet as an element in his elaborate and valuable researches into the compass question.

The following will shew what I mean by the need of a "more definite, searching, "more complete" means of testing:—A few months since I wanted a piece of the best and soundest plate iron, for use as a standard of comparison, because it is very essential to know precisely what value to assign to the action of needles of different sizes, as applied at different distances, &c., and whether as used parastatically or simply.

Under permission of the Captain-Superintendent, I went to the fountain-head in applying to the master boilermaker. He carefully selected a small portion of a partly used plate which had undergone and passed all the Admiralty tests. The piece was sent to my lecture room as a sample of the very best rolled plate which could possibly be procured; and as fit for the most important work. Before cutting off the sample (12 inches × 10 inches × $\frac{1}{2}$ inch), he had used the precaution of punching three or four burrs from various parts of the adjacent portions, for my

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approval; these certainly appeared to be of the finest quality. Now, if all these precautions were insufficient to procure me a sound piece of—say a square foot of—standard plate, there must be something wanted, even by so able a plate inspector as the well-known Mr. Boffey.

Now I have three distinct methods of ascertaining by magnetism the quality and condition of iron; and each of these admits of results being projected on paper as a diagram. What was my astonishment when on applying my three tests to this (supposed) superlatively good plate, they severally produced a diagram which utterly condemned the sample as totally unfit for boiler use! I naturally feared a pitfall—or suspected a trick; but returned the plate to the master boilermaker as certainly unsound, and even marked the faulty spot for his information.

He and his foreman then carefully examined it, as perhaps he only in the service *can* do; and his faith in the plate was evidently shaken. He at once cut the plate into strips, and found in those from that very spot a perfect corroboration in favour of magnetic testing. (I have the strips in this room, and will presently shew them). I should add that the plate is from a house of highest repute, and it matters not to me whether the faults be of *quality* or *condition;* consequences will in either case be the same.

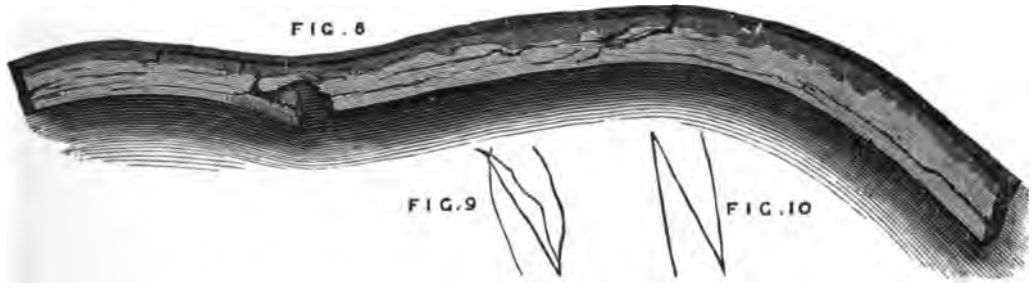

Fig. 8 shews one of these strips just as it came from the shears; Fig. 9 is a magnetic diagram of the faulty plate; and Fig. 10, the diagram of a good and sound plate for comparison.

I could shew *several* similar experiences (I have the specimens of some in this room), but will only in my Paper refer to one other.

A plate said to be from another eminent firm (but I *hope* this is a mistake), was placed before me for examination. It had passed the usual rigid test—perhaps I should say that one corner and the middle of one end had, and it was thought to be the very

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best in quality and condition. I condemned this also. (I will shew a piece of it to you presently). The magnetic test is unfailing; and this infallibility is just what all parties want.

I refer to this sample, the rather to illustrate a fact which I am unwilling to produce, and yet respectable firms in the iron trade will, I am sure, join in any attempt to remove what is one great burden on trade in plate iron. I had noticed that burrs taken from this plate suggested, even when no flaw was visible, a peculiarity in the middle of the three sheets, which, in manufacture, had been rolled into one plate. I placed a section under a microscope. It gave me the impression that the middle plate was of inferior quality. I must mention this because it cleared up a great perplexity which had previously attended some examinations of plate by magnetism. I re-examined several other samples for traces of the same condition, which, while quite free from absolute flaws, I could not consider sound; and, with an unpleasant conviction on my mind, *I found them.*

There needs no detail; it is enough to declare to a meeting of naval architects that if the interposition of inferior plates be by some men merely considered a trick of trade, *it cannot escape detection by the magnetic test.* But I submit to the Institution that the onus of detection need not rest with purchasers, when once respectable firms have the means of thoroughly testing their goods before issue.

Now this deeply concerns naval architects, and, indeed, all iron-shipbuilders; and in a lecture which, some months since, I gave to naval chief and other engineers, in the boiler yard at Sheerness, on the corrosion of marine boilers, I proved the truth of it. The conditions of several boilers on the spot were very instructive, and I have since had the advantage of witnessing the breaking up of some of these boilers; and have worked the harder to perfect a remedy for the enormous waste I saw. I ask why should some boilers be corroded and worn out in a single commission, whilst others last fifteen or sixteen years, and are still fit to be re-issued in excellent repaired condition for sea service? Let the wretched stuff called boiler plate, of which I will presently produce some samples, answer the enquiry.

Nothing contributes more towards this extravagantly wasteful state of things than the irregularities which I find in the difference of qualities of the plates used. I find better iron used in some portions of the boiler than in others. It is enough to have to mix (of necessity) rolled plate with forged and cast iron in the same fabric, and expose them to the action of brine, *without interlaminating different qualities in the same plate;* for every end section of such plates exposed to the action of the hot brine in the boiler, intensifies galvanic action, and favours corrosion.

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But I am afraid that so long as material is purchased in large quantities at contract prices, so long will there be temptation to play tricks with it, in iron as in other stores, and depreciations in quality will become a rule of trade. I have reason to believe that, from the competition which exists in the iron trade, manufacturers of really good iron are becoming gradually excluded from the market; and my judgment is founded on the general quality of the plate intended for boiler making, and of which I have examined so many varieties, and with so much surprise and dissatisfaction. It is important, then, to have the power of detecting these depreciations.

To obtain good iron, we had better pay double the present prices (I speak advisedly), for ships and boilers would last two or three times as long.

Do we not then, I say, need further aids in testing iron? Now, if I offer improvements herein, it will be useful to consider what are the impediments which prevent their immediate adoption?

1*st.*—The subject of magnetic testing is a novelty in which one has no experiences of other persons to consult for assistance.

2*nd.*—Those who are unacquainted with its principles over-rate its difficulties, and are apt to forget that in most real discoveries progress is gradual.

It is the combination of facts which constitutes this progress, or condemns a theory; but the combining of facts involves study, calm and deliberate. I have had the misfortune to be expected, by some, to advance without this; and because I could not, in the first instance, offer to those concerned a system of testing perfect in all its parts, it has been viewed by some suspiciously (I had almost read the word "superciliously);" but, Sir, if ever it meets public adoption, it will have been (under the permission of Captain W. K. Hall, the Captain-Superintendent at Sheerness) through the valuable assistance it first received from Mr. G. Morgan, the master smith, who has witnessed the whole of my successes (without one failure); and next, through the encouragement it met with at the Royal School of Naval Architecture at South Kensington, the distinguished principal of which caused it to be brought before this noble Institution.

3*rd.*—And again; the scale on which I have conducted my enquiries (as already noticed) has been limited.

As at Woolwich, I only need a few facilities (for which I really cannot afford to pay) in order to reduce my appliances to practice, in the best and most complete manner, by having time and opportunity, (which, indeed, Sheerness Yard might afford me), of quietly considering the merely mechanical question of applying the magnetic test.

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In giving me permission to work on a larger scale, either in a public or private factory (and not much is required) it would be a great mistake to expect me to work under the supervision of other persons; indeed, I should refuse to do so.

When all is once arranged, *then* let notes be taken of my work; or any observed particulars for or against the process; not while I am, perhaps, puzzling out a new and unexpected feature which might only require *precisely this* free and unfettered deliberation, in order to convert a new fact into another step of progress. It must be remembered that, while working under "supervision," every novelty—even every step—in sudden discovery is expected to be explainable at once; or it becomes registered against one's skill and intelligence.

A system of magnetic testing never can be satisfactorily completed without these facilities; the peculiar properties of magnetism render this requirement imperative; and I hope this is the consistent time and place for naming it.

Let a fair and reasonable assistance be rendered from any source, and I am much mistaken if the principal manufacturers of Europe (I can answer for those of France), will not gladly acknowledge the value of a discovery destined in perhaps abler hands than mine to confer a lasting benefit on not only naval architects—but on engineers—iron manufacturers—the sailor—the voyager—and indeed, considering the extensive uses in which iron has become an essential to the social and domestic as well as commercial conveniences of mankind, I may truly say, *to all posterity!*

DISCUSSION.

Mr. E. A. Cowper: Perhaps I omitted to gather it properly from the Paper, but I do not understand the method in which the test is applied. What is the nature of the test you apply?

Mr. Saxby: The use of the common magnet; but there are different combinations. I am not quite prepared to state them. There is a combination which I call a "parastatic" arrangement. Iron is tested by the oscillation of the poles of the magnets, which are passed along the iron in different directions, and under different circumstances. I use more than one magnet at a time. Here is a plate that was sent to me for examination; I condemned it; and there is a piece that came from it. (*Showing it.*) It is split in two. In punching it out, the two sides of the plate came apart. It is very good iron, but in a bad condition of manufacture. I have here strips of a plate that was cut; and the diagram of the condition, as shown by the magnet, again condemned it. The quality of the iron may be seen upon inspection. This is another. (*Producing it.*) It was cut from a plate of Bowling iron which had been selected as a standard for comparison; but the magnet condemned it as iron which, although good, was faulty in condition. Again, here is a piece of Bowling iron—I had not selected it in particular, but it was most convenient for me to

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get at. I dare say the same results would have occurred with regard to iron made by other manufacturers. It had passed all the usual trade tests without the discovery of any fault; but the magnetic test discovered a laminated portion. A strip of it was perfectly sound and good; but in other portions, the iron was, by the test of the magnet, found to be laminated and faulty. I have another specimen—a fair sample of the best Bowling iron; but that, from a mere accident of manufacture, is unsound. I pronounced it unsound before it was cut. All these cuttings have been made at the Sheerness Dockyard, under the observation of the master boilermaker and the master smith. Here is a piece of plate which the magnetic test showed to be fairly good. It is a fair sample of good boiler plate iron. I have also another sample, showing the most atrocious imperfections.

Mr. F. K. Barnes: It seems to me that the test will only indicate irregularity of manufacture. Will it shew the quality of the material? I merely ask for information whether the test would indicate anything further than irregularity of manufacture as Mr. Saxby would seem to imply?

Mr. Saxby: If there are flaws in the iron, or if the mass contains anything but iron, the magnet will detect it, and it will also detect the crystalline condition of the iron. There is a very peculiar vibration of the magnets where the parts are crystallized.

Mr. John M. Henwood: I should like Mr. Saxby to describe the method he uses in applying his magnet to plates.

Mr. Saxby: I am not prepared at present to describe it.

Mr. J. M. Henwood: I wish to know whether the magnet is applied on the edge, or upon the surface of the plate?

Mr. Charles Lamport: Mr. Saxby has mentioned the name of the Rev. Mr. Scoresby in connection with the subject of magnetism. I have seen the Rev. Mr. Scoresby perform the most curious experiments, and it strikes me, from careful attention to the subject, that one of the phenomena which he showed in connection with the magnetism of iron would prove to be a great drawback to the infallibility of Mr. Saxby's test with regard to the quality of iron—I mean the almost instantaneous change in its nature from a condition non-magnetic to magnetic, through simple percussion. It seems to me that it is quite possible in a large plate, if a portion of it were subject to molecular motion through percussion, as Mr. Scoresby showed when in a direction north and south, for the plate to become, in parts, more perfectly magnetic than in others; and, when Mr. Saxby applies his test with regard to the manufacture and condition of the iron, we might be dealing with an unknown enemy in the shape of magnetism in the plate itself.

Mr. T. A. Rochussen: I had hoped that others more competent than myself would have taken up this important question. With regard to the trouble the inventor has taken, we must all feel that he has been devoting himself to a very important matter; but I think it as well that we should endeavour, as far as possible, to investigate its practical value. It is very pleasant, in one sense, to have the means of detecting a flaw; but, on the other hand the manufacturer of iron, and the user of iron, are both impressed with the notion that it is next to commercially impossible to produce a chemically pure iron plate. In every iron we have an admixture of more or less sulphur, or more or less carbon. We cannot make it chemically pure. If we have an instrument that tells us there is a flaw, but does not tell us the

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extent of that flaw, or what the extent of the chemical impurity is, our difficulties are not removed. I think we should always be steering clear of a shoal of uncertainty, for "Where ignorance is bliss 'tis "folly to be wise." It may be that a boiler plate, or a large plate, contains imperfections which, the magnet is sufficiently susceptible to point out; but, for all that, the plate in question may not be, in practical use, a bit the worse; and it is unfair to endeavour to call upon manufacturers to produce a high class iron, and then take as a test that magnificent iron which is used at the Enfield factory. It is iron known as "Marshall's Iron." It is carefully made in small skelps about 10 inches long, 5 inches in breadth, $4\frac{3}{4}$ inches at the top, and $\frac{5}{8}$ths of an inch in thickness. We frequently read of fine Yorkshire iron, as fine as can possibly be obtained, which will melt like tin or lead, and which is altogether the very aristocracy of iron production. If that were made on such a scale as is required in a ship, or for the purposes of boiler plate, we might as well build our ships of copper itself. It is out of the question to compare that with ordinary iron. If, with regard to iron which is as pure as it can possibly be made by the makers of iron, you find a flaw in a gun-barrel, what would you expect to find in a large plate? I am happy to say, as an advocate of steel, that in the steel barrels which were tested at Enfield, none of these failures indicated by the magnet were found, which is another argument for the substitution of a more homogeneous metal. I hope that others will take up the question better than I have done. Before I sit down I will point out this:—We have before us some specimens of iron plate; I see in them flaws and cracks: they may be flaws in welding: it is quite possible that the injury is simply mechanical injury done by the ordinary tearing apart, punching, or shearing. Will the magnet shew from what source the fault arises?

Mr. E. A. Cowper: I would say a few words with reference to "Marshall's Iron." It is first rolled and cut up into very small pieces, and those pieces are put into a mill with sand and water until every piece of the iron is perfectly bright and clean. They are then washed in clean water and piled. When the gun-barrel comes out you can scarcely see any black or "grays" anywhere. It is really remarkably good iron; but if we were to make boilers of such stuff as that, as Mr. Rochussen has said, we might as well go to copper at once. I do not think that in all cases we are going to trust to an instrument of which we know nothing. I do not think manufacturers will trust to a sort of divining rod; neither do I think persons whose duty it is to examine boiler plate will trust to it. It is a sort of step in the dark which we do not quite understand. I think as practical men we must know what it is that we are trusting to. If it is a secret, I do not think it should have been brought before this Institution, and I do not wish to ask Mr. Saxby to disclose it; but if it is not a secret, I think that we should be more enlightened upon the subject. *How* are we going to test the iron? At present I understand nothing on earth about it.

Mr. Lewis Olrick: The question is of the greatest importance to all connected with iron manufacture. You will, no doubt, have gathered from Mr. Rochussen, that he is connected with the manufacture of iron; but when you come to be the manufacturer of ships, boilers, or girders, you take the responsibility off his shoulders upon your own. It is all very well to say it is better to be ignorant of what the iron is, because ignorance is bliss; but with reference to a boiler, if an explosion were to take place, and lives were lost, the manufacturer would immediately be called upon by the coroner and made responsible for the mischief done; and it would not avail for the manufacturer to say, "I never tested it, and I do not care." The question really becomes, commercially, a question of pounds, shillings,

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and pence; for if people will buy cheap girders, cheap ships, and cheap boilers, the maker cannot afford to employ first-class iron; but, if on the other hand, they will not commit themselves to the argument of Mr. Rochussen, that "ignorance is bliss," it is their duty, whether shipbuilders, boiler-makers, girder-makers, or iron manufacturers, to produce a first-class article for a first-class price. It is a question which I am personally interested in, for this reason—I have at the present time a number of contracts, where I am responsible for what I produce in the way of boilers. I have now undertaken a contract where I have a minimum working pressure of 150 pounds per square inch, and if I were to act upon the same principle as Mr. Rochussen, I should perhaps one day be called on to answer for loss of life. I will explain to you the manner in which I examine my plates. I take the plate, and divide it into squares. I mark off two inches along the edge of the plate both ways, and then strike chalk lines from all those marks; I get thereby, a number of small squares, two inches each way, which makes four square inches. I then let one of the most careful and competent men, a man that can be trusted, take a very small hammer, not much larger than a watchmaker's hammer, and test the whole of the plate by tapping each of those squares. That is the best way of finding out the imperfections, blisters, and laminations in the plate. I am quite sure that the imperfections in the plate which Mr. Saxby has shown would have been detected by my little hammer. In the manner I have just described I detected, out of 40 tons, twelve plates which were returned because they were defective in different ways—there were either blisters or laminations in them; or they were pock-marked, so deeply as to penetrate $\frac{1}{8}$-inch into the plate. Such plates I should never put into a boiler. I should like to know from Mr. Saxby what is the particular result of his test. First, I would ask, can I apply his test to steel plates? Next, when I receive the plates that are to be put into boilers to stand the very high steam pressure which I have mentioned, can I apply the test myself, and at what cost? Or if I cannot do it myself, will Mr. Saxby favour me by stating what it would cost me to have the plates examined thoroughly by his system; and if he condemned them, will the iron or steel works submit to his test; or will they merely state that they will not guarantee the plates sent, but that they will use every endeavour to ensure the supply of sound plates by making them larger than required, and by cutting, shearing, and bending them, which is a very good test for steel plates? Mr. Saxby has mentioned that it is best to put good and expensive plates into your work. I answer, yes; if you get a good price for it no doubt that is the best remedy; but if you get the lowest price (and I think, as a rule, only the very lowest tender is accepted) what are you to do? Are you to have the pleasure of making girders and boilers without getting any profit whatever out of them? If you can maintain, as large firms do maintain on account of their reputation and good name, a large price, you can do it; but if you are a beginner, you cannot as a rule get the same price as the large manufacturers obtain.

Mr. ROCHUSSEN: Mr. Chairman: I rise for the second time simply to defend my character. In what I said I wished merely to point out that it would be folly to fish for certain flaws, unless you had the means at command to ascertain to what extent the flaws, if flaws they be, exist. I believe I am well known as having been a worker in the direction of test for many years, and would still advocate the keeping up the high quality by all practicable means.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): I believe the question before us is rather one of science than of work, or the nature of the iron. In the year 1830 a Frenchman came to our Government precisely with a similar plan, to test iron, and to determine where any of the

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shuttings came on; and he found that, wherever the iron had been divided, even where it was not perceptible to the eye, he could detect the shuttings, where incomplete, by the magnet. That person's name was Revère. He entered into partnership with one of the late captains of Greenwich Hospital (M. Sweny), and in 1830 I was supplied with a series of needles or magnets which had four poles. When you passed from the extreme to the half distance to the centre, it changed and became a north or south pole, and so on. He then formed his magnet of three different portions. He made it a diamond shape, and welded on bars at the end so as to obviate, as he thought, the middle points of his magnet. In consequence of such a compass with these needles being supplied to me, I got Mr. Cary of the Strand to make me a series of bars of five different parallels of clock-spring, with mica between; each of them connected with opposite poles, so that when the whole was screwed together, it became a compound magnet, and could not be upset by concussion. As regards Mr. Scoresby's experiments; he was the first to prove that a common bar, even a poker, held vertically and struck a certain number of blows upon the upper end becomes almost immediately a magnet. Owing to his having taught me that, I saved my life. I got bewildered in the caves of Bermuda. Having an iron jumper I had been at work with, I struck it, held vertically, with a hammer until I made a magnet of it. I then suspended it with a piece of twine and found my way out. Now as to the mode of application. If there is to be any reliable mode of application let it be scientific, and let it stand such a test as it would be subjected to if it went to the Royal Observatory at Greenwich—that is, first determine the actual axis you have to deal with, strap the object to be tested on a parallel wooden framing which will enable you, with your box, in a wooden vessel, to slide it truly *parallel to the rhumb* from end to end, and thus observe all the deflections. With reference to the influence of any metal brought into contiguity with the magnet, I should mention that I was at work at my Magnetic Observatory at Simon's Bay, at the Cape of Good Hope, when the late Sir James Ross, who had conducted the whole of his experiments upon that same spot, came in. I observed, "Well, Ross, what did you take your "observations with—what chronometer did you use?" He replied, "I used this," showing me his pocket chronometer. I said, "Will you be good enough to lend me that chronometer, and allow me to "walk at a distance of 10 feet round the tent and you will find that the whole of your observations* have "been greatly affected by it." And so it was. He was perfectly satisfied that his chronometer, which was in his pocket at the time he had made his magnetic observations, had in a degree vitiated them—so very delicate and sensitive is the magnetic needle when properly suspended and furnished with reflecting mirrors, which give you the thousandth part of a degree of arc. Now, in the process of rolling iron, we all know that the iron which is used for boiler plate is *rolled* over and over again, and is not like our armour-plates, where we have plate after plate, one laid over the other and welded together. But let us go back to the formation of railway iron by Muntz and his partner. There, the railway iron used has the upper part of it of wrought iron, and the under part of it of cast iron. And how were those ingots made? Old chain cable, scrap iron, in fact anything that they could get hold of, was put into the moulds, and the metal from the furnace was turned out upon it, and it was so fused into ingots, and then rolled out. I have no doubt that if those bars which were exhibited in the Exhibition of 1851, and were assumed as the *acme* of perfection of railway iron, had been tested, we should have had all these variations. The question is, whether they are the worse for it? I think not; I think

* As explained by Dr. Scoresby, Brit. Assoc. (1848, Swansea.)

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that those railway bars were quite as good, for the time they lasted, as any other iron bars that have ever been manufactured. I am a workman myself, therefore I know, pretty well, what iron is when you come to deal with it, and how very tantalising and distressing it is, after having taken up a piece of work, and worked, possibly, four or five days at it, to find it defective. In dealing with brass we are obliged to hammer it; and no good work, either in astronomical instruments, or screws, or anything of a similar kind, is produced unless the metal is sufficiently hammered and condensed. In forming our iron ships they all become magnetic, in proportion to the percussion in the rivets, and imbibe a certain degree of magnetism, which acts oppositely to the iron itself, if the rivets have not been hammered. The man who "demagnetized," as he calls it, the *Northumberland*, supposed that by forming a galvanic circle, as he described it, in that ship, he would be able to take out all the induced magnetism. I very much doubt whether he did so, though he considered that he had.

Mr. C. W. MERRIFIELD, F.R.S.: I can tell you, Sir Edward, that he did not. He succeeded in giving local polarity.

The CHAIRMAN: No doubt you may examine metal plates of 6, 8, or 12 inches in thickness, and you may find defects of this nature throughout. But wherever there are laminæ you must have that defect multiplied, for there is a change in magnetism. But are they in reality worse? Would you reject a plate of 12 inches because you discovered a variety of such apparent flaws in it? I should say, certainly not. It is of perfect value for the purpose for which it was intended. Many of these defects are produced by using bad coal at the time you are heating the plate for rolling. If there is the smallest quantity of iron pyrites, or of sulphur, at the time the plate undergoes the process there is a cavity, and when the next plate comes to be welded to it, the plate which has to be welded to the next one will not stick; just in the same way as with Armstrong's guns. Armstrong, in his gun, heated the spiral, then brought it out into the air. It became oxydised, the scales did not tumble out, and the welds thus produced were not perfect. But I believe they have since obviated that. When his chief man was at work at Woolwich I pointed this out to him. He said, "I believe you are quite correct; we have not a perfect weld in any one of our spirals." I should have much liked Captain Selwyn to have spoken upon this subject, because in a lecture which he gave us at the United Service Institution, he illustrated what I am about to observe, namely, that if you cut a piece of iron in two, after you have examined it from end to end, and apply the two ends in plain water, you get galvanic action immediately. Although that iron previously may have defied all your efforts, from end to end, the moment it is cut in two it becomes a pair of magnets. I am not at all opposing the views of the lecturer, but I think it due to him that I should mention these little things which have passed through my mind, and occurred to me in practice.

Captain JASPER H. SELWYN, R.N.: I may be in order in making one or two observations. I know perfectly well that a bar, as I showed, would exhibit different states with regard to its galvanic action; but I am not at all prepared to say that I could have detected in that bar any difference in its magnetic state except after percussion. What I wish the Meeting particularly to remark, and I think it is a common-sense observation, is this:—Mr. Saxby is in the beginning of this investigation. It is a most interesting one, because, if it affords a test at all, it is a test which can as easily be applied by the manufacturer as by the buyer of the iron, and, consequently, the manufacturer ought to hail it with

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as much pleasure as the buyer, since he would be delighted to have the means of avoiding the sending away of bad plates which may do him no credit. It is not necessary to make a specially good quality of iron because you have a specially good test, but the great advantage is that you may know which is good iron and which is not. Mr. Saxby has shown you, clearly and distinctly, that he not only can ascertain that there is a fault, but, even in this early stage of the investigation, he can shew *nearly* its extent and *nearly* its quality. I think it is too much to ask of him that he should at once shew us everything that experience alone can teach; and, if we fairly look at the thing, it is giving to all men of science a new power of determining the state of iron which they have no other means of ascertaining. It is a most valuable discovery, and not at all one to be thrown cold water upon for one reason or another. I do not think anybody need be afraid of it. We should all welcome and hail with delight any test for telegraphy, or anything which would give us the means of testing the state of our cables above, as well as under water, or of ascertaining what our ships would do without sending them to sea, or trying them over a measured mile. We have not got that yet, but he offers us a remedy which is almost an equivalent to it. I have always a great dislike to hear anything said against the advancement of science; but, independently of that, I think the maxim specially applies to a brother sailor that you are always to assist a known friend to the utmost of your power.

Mr. SAXBY: I think I may say at the commencement of my answers that almost everything which has been mentioned, and almost every question that has been put to me this evening, has been anticipated in my Paper, and those who carefully read it will see that I do take advantage of the several positions of the iron, although iron having stood in different positions for a considerable time, acquires peculiarities of magnetic condition. This is discovered in the very process of testing, and I take care to divest the plate of it before I finish my operation. Sir Edward Belcher just now remarked that everything of this nature ought to be founded upon science. I believe I have taken the recognised laws of science and the laws of nature as my foundation. As regards the remark made by Mr. Rochussen, I would again refer to my Paper by saying that when Colonel Dixon witnessed with me the action of the metal upon the needle, and acknowledged that there was some defect in the barrel, I said, "It does not interfere at all with the value of the mass—it is not of sufficient importance to interfere with the usefulness of the barrel." I know it is not possible, and we do not expect it to be possible, that the iron of commerce should be pure. The reason I am in so much need of further assistance is that I require to be informed upon precisely the same point as that upon which you yourselves require information, namely, what value we are to attach to the oscillation of the needle when brought into contact with iron in certain directions—that is the main point which I am desirous of ascertaining. In fact that one thing prevents my answering such questions as were put to me, when the suggestion was made as to its being a secret. It is no secret. I mentioned openly before this Institution last year that I had no personal interest in the question, and that I did not intend to take any. I do not mean to say that I may not be induced by success to seek some slight personal interest in it. I mention this because I wish to divest your minds of the idea that, as far as I am concerned, I wish for any secrecy. If there is any apparent secrecy, it arises from the fact that I desire to confirm certain things which I do not yet feel quite justified in putting before the public in their present state, as perfect. It is very easy to make assertions, but not always so easy to maintain them. I am not quite unknown to the world, and through life have been very cautious not to put forward theories which I

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could not substantiate. I think great caution should be exercised when a man like myself presumes to interfere with what, really, more concerns the interests of another class of men than himself. This, I think, answers what Mr. Rochussen said when he remarked that I did not tell you what was the amount of fault. I could tell you, because I understand it myself; but I do not feel in a position, at present, to state it. So much depends upon the size of the needle in comparison with the mass upon which you are operating, that it would be imprudent for me in the present stage of my investigations to presume to lay down rules upon that subject before those rules are perfectly within the scope of my powers. But I apprehend that a very little practice would enable me to furnish you with materials upon which you might safely rely. I only ask for that practice; that is all I ask. Give me the practice, and in exchange I will give you additionally confirmed rules that are infallible. A gentleman near me spoke of the question of the purity of the plate being one of pounds, shillings and pence. I say the same. I do not suppose that it is necessary upon all occasions to have the best iron. I would only remark this,—that Sir William Armstrong cannot get perfect welds in the spirals of his guns; whereas, if he could get perfect welds, he would not require one-half the weight of iron in the strengthening parts. While at Woolwich, I had the opportunity of testing one of the outer coverings of a very heavy gun. I tested the part which covers the breech, and I can only say that I was perfectly amazed at the purity and goodness of the condition of that outside mass of iron. It has been asked whether that which I profess to be able to do applies equally to steel as to iron. I answer, "It does." Many of the steel barrels which I tested at Enfield were as easily tested as iron could have been. In order to save time, I only required to be told whether they were steel or iron. If they had refused to answer me I should have found out for myself. I say that steel, if not specially magnetized, is much more easily tested than good iron. It is the work of a few seconds to ascertain whether it is steel or iron. I am not answering these questions in the order in which they were put, but it has been said by one gentleman (Mr. Olrick), that he had no doubt if the plate had been put into his hands, a small hammer would have detected the fault. I have no doubt that that may be so when the fault is a gross one. But he must remember that these ½-inch plates had been subjected to that test by one of the most able men in the kingdom. I believe I am justified in saying so much in mentioning the name of Mr. Boffey, whose opinion has been referred to upon several occasions by the Admiralty on account of his great skill and knowledge in testing iron. He had very carefully tested by the hammer, as well as by all the trade methods, the whole of this plate before he brought it to me, and he pronounced it to be so thoroughly good that I was allowed to take it as a specimen, in order that from it I should possess a perfect standard diagram for comparison with diagrams generally. Then with regard to laminations: laminations occur in good iron as well as in bad iron. They are not at all confined to bad iron. I say that good iron which is laminated loses a very great portion of its strength, and is not what it appears to be. To have a means of testing these laminations would be of great utility. My third mode of testing is to ascertain the position of the fault. I first test it in one direction with a certain arrangement of magnets. I then take my second plan, and add to the diagram; when that is done I take my third plan, and show the precise spot in which the fault lies; and I assert publicly that I have never, upon any one occasion, failed in pointing out the cause of the deflections of my magnet, and the position in which the fault or flaw was to be found. I repeat that if I have not quite so well confirmed the exact value to be attributed to the oscillations of the needle as might be wished, it is but fair to suppose that with a little more practice I shall accomplish that object. I thank Sir Edward Belcher for having

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mentioned to me that a Frenchman had approached the subject. I confess I was somewhat surprised to hear it, for I had never heard it suggested that this subject had been previously taken up by any other person. I would add one word with reference to scrap iron. I mentioned when I had the pleasure of speaking upon this subject last year (and ought to repeat it) that as regards scrap iron, I was passing through the boiler shed at Sheerness when the paddle-shaft of the *Virago* happened to be in the lathe. In passing, an officer who was with me, said, "Here is something which will suit you—why not try this?" I took my common pocket magnet. It so happened that the shaft was lying in a convenient direction for the application of the test. I put a mark on a certain spot, and said, "Something is wrong here, depend upon it." That part had to be turned away to a depth of 2 or 3 inches. The next day I was told by the same officer that, in turning it, down at that very spot they came upon a flaw. I then directed my attention to the rest of the shaft, and found other flaws, though I could not at that time, from want of experience, say that they were of sufficient importance to condemn the shaft. I want myself to know how far I may go in pronouncing an opinion as to whether a manufactured article is trustworthy or not, because it is the custom of manufacturers to put surplus metal to meet contingencies—a sudden strain, or anything of that kind. I think I have left nothing unanswered. If I have omitted anything, I should be thankful to be reminded of it.

Mr. OLRICK: What I wished particularly to know was, whether I could apply the test myself, and at what cost, and, if I could not, at what cost you would apply it for me?

Mr. SAXBY: My first answer to that would be that, it being so very simple, a child who had once seen it done might apply it. It is the work of ten or twelve seconds, and as to the cost it would be absolutely nothing. When once you get the compass or magnets arranged which would entail the expenditure of a few shillings, the cost of testing is absolutely nothing. The cost is nothing,—the trouble is nothing,—but the pleasure is very great.

The CHAIRMAN: I am sure you will all thank Mr. Saxby for the trouble he has taken in this matter. As I told him when he last addressed us upon this subject, I do hope that he will persevere, and that he may eventually attain success.

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ON THE CALCULATION OF THE STRESS IN PROPELLER SHAFTS.*

By W. J. Macquorn Rankine, Esq., C.E., LL.D., F.R.S., Assoc. Mem. Council.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; Vice-Admiral Sir Edward Belcher, K.C.B., Vice-President, in the Chair.]

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1. Through a long series of practical trials, extending over many years, it was ascertained by Lieutenant David Rankine (H. P. Rifle Brigade), and by the author of this Paper, that the greatest stress which the wrought iron axles of very smooth running railway carriages, travelling at speeds not exceeding 12 miles an hour, would safely bear, when made of the best material in the best way, was 9,000 pounds on the square inch (or about 6·3 kilogrammes on the square millimètre). Any defect in materials or workmanship, when exposed to that stress, was always found to cause the axle to give way in the end; though sometimes not until it had run for more than three years. The immediate breaking stress was not directly ascertained; but it is probable that the factor of safety was between 5 and 6. A greater factor of safety, or, in other words, a smaller limit of the intensity of stress, is, of course, required when the motion is rougher than it was in those carriages.

2. According to the ordinary method of calculating the greatest stress in propeller shafts, the moment of the twisting action upon the shaft is alone taken into account; and when that method is applied to examples taken from actual steam vessels, results are obtained approaching very near to the limit already stated. For instance, 8,000 lbs. to the square inch is a not uncommon value of the intensity of the stress in a propeller shaft, as calculated from the twisting action alone.

3. But the real intensity of the stress is greater still; for, with the twisting action, there is always combined more or less of a bending action, produced partly by the weight of the shaft, and partly by its reaction when the vessel pitches and heaves with the waves. The object of the present Paper is to give rules for calculating the total or

* Received 4th March, 1869.

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resultant stress, produced by the twisting and bending actions combined; and to illustrate them by an example.

4. Twisting Action.—*The greatest twisting moment* is to be calculated from the indicated horses' power of the engines, as follows: Multiply the power by 33,000 in order to reduce it to foot-pounds per minute; and divide the product by 6·2832 times the number of revolutions of the shaft per minute. The quotient will be the *mean twisting moment*, in foot-pounds. (For kilogrammètres, the multiplier is 4,500 instead of 33,000). The *greatest twisting moment* is greater than the mean twisting moment, in a ratio which may be estimated at about 1·6 for a single engine, 1·11 for a pair of engines with cranks at right angles, and 1·05 for three engines with cranks at equal angles.

When British measures are employed, the greatest twisting moment, having been computed in foot-pounds, is to be multiplied by 12, to reduce it to inch-pounds.

To find the *greatest intensity of the stress produced by twisting*, multiply the greatest twisting moment by $\frac{16}{\pi}$ (= 5·1 nearly) and divide by the cube of the diameter of the shaft. In symbols, let M be the moment, d the diameter, and q the *twisting stress* (as it may be called) then

$$q = \frac{5 \cdot 1 \, M}{d^3} \quad . \quad . \quad . \quad . \quad . \quad (1).$$

5. Bending Action.—The greatest stress produced on the particles of a horizontal cylindrical shaft, by the bending action of its own weight, is equivalent to the weight of a column of iron, whose height is a third proportional to the diameter and the span between the bearings.

In symbols, let l be the span between the bearings (in inches, if British measures be used); d, the diameter; w, the heaviness of iron (= ·278 pounds per cubic inch, or 7,690 kilogrammes per cubic mètre); p, the greatest *bending stress*, as it may be called; then

$$p = \frac{w \, l^3}{d} . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

The *reaction* of the shaft, produced by vertical oscillations, as in pitching and heaving, bears the same proportion to its weight, that half the extent of the oscillations bears to the length of a pendulum which keeps time with them. Let m be that proportion, then the bending stress is increased to

$$p = (1 + m) \frac{w \, l^3}{d} . \quad . \quad . \quad . \quad . \quad (3).$$

In a vessel that follows the vertical heaving of the waves, the value of m is nearly the sine of the wave slope; say 0·25 in extreme cases, and 0·125 in ordinary cases.

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6. Resultant Stress.—The resultant stress, due to the twisting stress q, and the bending stress p combined, is found by a formula which has been demonstrated by writers on the internal equilibrium of elastic solids, that is to say:—

$$s = \sqrt{\left(q^2 + \frac{p^2}{4}\right)} + \frac{p}{2} \quad . \quad . \quad . \quad . \quad (4).$$

where s denotes the intensity of the resultant stress.

7. Numerical Example.—In the following example, the results are not computed beyond four significant figures:—

Indicated H.P.		5,500	
Multiply by		33,000	
Divide by	6·2832)	181,500,000	foot-pounds per minute.
Revolutions per minute ...	54)	28,890,000	quotient, nearly.
Mean twisting moment		535,000	foot-pounds.
For a pair of engines, multiply by		1·11	
Greatest twisting moment ...		593,850	„ „
Multiply by		12	
Greatest twisting moment ...		7,126,200	inch-pounds.
Multiply by		5·1	
Diameter, $16\frac{1}{2}$ inches			
Diameter^3, ...	4,492)	36,340,000	product, nearly.
Twisting stress, q = ...		8,090	pounds on the square inch.
Span between bearings, 25 feet =		300	inches.
Divide by diameter		$16\frac{1}{2}$) 90,000	square of span.
Third proportional		5,455	inches.
Multiply by weight of a cubic inch of iron		0·278	pounds.
Bending stress by weight alone		1,516	„ on the square inch.
× estimated value of $1 + m$, say ...		$1\frac{1}{8}$	
Bending stress by weight and reaction = p = ...		1,704	„ „ „ „

Resultant stress:—

$$s = \sqrt{\left(q^2 + \frac{p^2}{4}\right)} + \frac{p}{2} = 8{,}987 \text{ pounds on the square inch;}$$

being practically equal to the greatest safe stress of 9,000 pounds on the square inch, mentioned in § 1 as applicable to smoothly running railway axles at low speeds.

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8. It seems very probable, that if the method of calculation now described were applied to actual examples of propeller shafts, many instances would be found in which the resultant stress reaches, or even goes beyond, the utmost limits consistent with safety; and it is therefore laid before the Institution for their consideration, and for that of shipbuilders, and marine engineers in general.

9. Rules for Designing Shafts.—The conditions which the diameter of a shaft ought to fulfil, are expressed by the following equation derived from equation 4.

$$s^2 - sp - q^2 = 0; \quad . \quad . \quad . \quad . \quad . \quad (5).$$

in which, for s, is to be put a safe working value of the resultant stress (say 8,000 pounds on the square inch, or 5·6 kilogrammes on the square millimètre), and for p, and q, their values in terms of M, l, w, and d, as given by equations 2 and 1 respectively. The equation then becomes of the *sixth order;* and it is to be solved so as to find d. This can be done by approximation only; and a convenient method of approximation is as follows: Assume for q an approximate value q', somewhat less than that of s (say, $q' = 0{\cdot}9\ s$). Then calculate an approximate value d' of the diameter, from equation 1; *viz.:*

$$d' = \left(\frac{5{\cdot}1\,\mathrm{M}}{q'}\right)^{\frac{1}{3}}. \quad . \quad . \quad . \quad . \quad (6).$$

Then calculate for p, an approximate value p', from equation 3, *viz.*:—

$$p' = (1 + m)\frac{w\,l^2}{d'}; \quad . \quad . \quad . \quad . \quad . \quad (7).$$

And from the approximate value of p' calculate a second approximate value of q, as follows:—

$$q'' = \surd\left(s^2 - sp'\right) \quad . \quad . \quad . \quad . \quad . \quad (8).$$

Should this agree with the first approximate value q', the approximate diameter d' will answer; and should there be a difference, a second approximation d'' to the required diameter is to be computed as follows:—

$$d'' = d'\left(\frac{q'}{q''}\right)^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad (9).$$

When, as is usually the case, the difference $q' - q''$ is small compared with q', the following formula for the second approximation is sufficiently near the truth:—

$$d'' = d'\left\{1 + \frac{q' - q''}{3\,q'}\right\} \quad . \quad . \quad . \quad . \quad (10).$$

A third approximation might be found by repeating the process; but the second approximation will in general be accurate enough for practical purposes. Should q'' prove to be greater than q', the correction in equation 10 becomes negative; that is, the second approximation to the diameter is less than the first.

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10. EXAMPLE OF THE RULE.—$l = 300$ inches, as before.

Twisting moment M = ...		7,126,200	inch-pounds, as before.
Multiply by		5·1	
Divide by q' = ...	7,200)	36,340,000	product, nearly.
First approximation, d'^3 = ...		5,047	
„ „ d' = ...		17·15	inches.
Divide by d' = ...	17·15)	90,000	= l^2, as before.
		5,248	third proportional.
Multiply by $(1 + m)\, w = 1\frac{1}{8}\, w$ =		·313	
First approximation, p' = ...		1,643	pounds on the square inch.
Intended resultant stress, s = ...		8,000	
Multiply by $s - p'$ = ...		6,357	
Second approximation, q''^2 = ...		50,856,000	
„ „ q'' =		7,131	pounds on the square inch.
First approximation, q' = ...		7,200	
$q' - q''$ =		69	

Second approximation to the required diameter:

$$d'' = 17{\cdot}15\left\{1 + \frac{69}{3 \times 7{,}200}\right\} = 17{\cdot}21 \text{ inches.}$$

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ON THE RESISTANCE OPPOSED BY WATER TO THE MOTION OF VESSELS OF VARIOUS FORMS, AND THE WAY IN WHICH THIS VARIES WITH THE VELOCITY.*

By JOHN I. THORNYCROFT, Esq., C.E.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; Vice-Admiral Sir EDWARD BELCHER, K.C.B., Vice-President, in the Chair.]

FINDING that the accepted law of the resistance of vessels, varying as the velocity squared, does not hold good even for low velocities, I was led to investigate the elements of such resistance, with a view to obtaining a formula which would give results more in accordance with those found in actual practice than are given by the above mentioned law.

In this Paper the results of some of the most extreme forms that occur in practice are compared with those estimated by a new formula; the object being to prove that the same may, without much error, be applied to another form very different, but still preserving the quality of continuity.

The result of this comparison is most easily seen in the annexed diagram, in which the I. H. P. and velocity in knots per hour are assigned to any point by suitable scales, so that the performance of a vessel may be represented by a single curve line. In this diagram the results of actual trials are represented by the centres of small circles, and the estimated performance by drawn lines: points in these lines have been calculated by the formula:—

$$\text{I. H. P.} = Vh\left(\text{S}f\frac{3n}{2n+l}V^{1\cdot7} + \phi\text{S. C.}\frac{n^{\frac{1}{2}}+3}{l^{\frac{1}{2}}+3}V^{3\cdot7}\right)$$

where S = the wetted surface, V = the velocity in knots, h, f, n, C, constants, l = length, and $\phi\,\text{S} = \int \sin^{2\cdot5}\theta\, ds$, where ds = small part of the surface S, and θ the angle made by this part of the surface to the line of motion of the vessel.

The entire resistance is thus considered in two parts, separately. The way in which these vary with change of velocity has been determined partly from the flow of water

* Received 3rd February, 1869.

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in pipes (a suggestion for which I am indebted to Mr. Elder); and experiments of this kind seem to shew clearly that the resistance due to S does not increase so fast as V^2. The entire resistance of those vessels of which I have several trials, including different velocities, and thus giving the rate of increase, increases much faster than V^2; this is the case even in the *Warrior*, at a speed less than 12 knots. From this it follows of necessity that the remaining part of the resistance must have a great rate of increase with increase of V.

The ticked lines on the diagram represent I. H. P. varying as V^3, and shew how this differs from the actual trials given.

The efficiency of the engines and propeller is taken uniformly at ·68, this being, I believe, considered a good mean by Professor Rankine.

Mr. Elder made experiments with a model of rectangular plan, and having a floor curved only in the direction of its length; in width, the model was composed of separate parts. The resistance of the entire model was found to be only equal to the sum of its parts tried separately.

I have now to call your attention to a Table of actual and estimated performance. The contents of the several columns of this Table are shown by the headings, the first being the date of trial; second, mean draught of water; third, displacement in tons; fourth, indicated horse-power; fifth, indicated horse-power, by formula, actual speed; sixth, actual speed; seventh, estimated speed at actual horse-power; eighth, wetted surface; ninth, function of surface depending on sharpness of vessel and its surface.

[TABLE

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TABLE OF ACTUAL AND ESTIMATED PERFORMANCE.

Name of Vessel.	Date of Trial.	Mean Draught.	Dispt.	I. H. P.	Estimated I. H. P.	V.	Estimated V.	S.	ϕ S.
Warrior	17th Oct., 1861	25-11½	8852	5469	5469	14·356	14·356	28260	169·9
,, ...	25th Oct., 1861	25-11½	8852	2867	2910	12·174	12·13	28260	169·9
,, ...	...	25-11½	8852	1988	2024	11·040	10·99	28260	169·9
Bellerophon ...	...	22-10½	6808	5989	6479	14·00	13·75	22450	258·6
,, ...	...	23-5	...	3725	3750	12·15	12·13	22820	268·7
Enlarged Bellerophon	...	26·1	10116·	...	8527	...	14·13	29230	336·7
Circular Ironclad ...	...	16-0	10116·	...	8527	...	13·42	44806	328·7
Hercules	1st Jan., 1869	...	8680·	8527	8977	14·69	14·54	...	...
,, ...	...	...	...	4044	3984	12·125	12·18	...	...
Holyhead Boat ...	...	...	1900	4160	2350	16·28	19·11	12614	24·95
Quito	...	...	1200	1396	1324	13·2	13·4	7379	51·89
,, ...	...	...	1200	830	840	11·8	11·76	7379	51·89
,, ...	...	...	1200	640	653	10·97	10·92	7379	51·89
,, ...	...	...	1200	410	432	9·8	9·65	7379	51·89
Water Lily	July, 1868	1-5	4·5	8·02	8·67	7·275	7·14	265·	·316
,, ...	...	1-5	4·5	3·17	2·84	5·29	5·48	265·	·316
,, ...	...	1-5	4·5	1·94	1·81	4·6	4·7	265·	·316

NOTE.—The performance of the *Hercules* is estimated on the supposition that the hull is similar in figure to that of the *Bellerophon*. The constants have been arranged to give the *Warrior's* speed correctly at 14·356 knots. The figures for the *Holyhead Boat* were taken from a trial of 64 miles against tide.

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Calculation for H. M. S. "Warrior" at 25–11½ Draught.

[To estimate ϕ S from the body plan, the surface of vessel is divided into equal areas; the tangent of the angle for each of these areas is transferred from the body plan to a suitable curve, by means of which the sin $^{2\cdot5}\theta$ can be read off. The sum of these quantities is multiplied by (112) the area of one of the parts into which the surface is divided; and by (2) because only one side of the vessel is measured $= \phi$ S nearly.]

Example:—

	Initials.	BANDS.								
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	
STERN	1	·0437	·0509	·0555	·0385	·0137	·0105	·0031	·0004	
	2	84	116	154	172	171	140	82	31	
	3	23	50	70	83	84	68	42	18	
	4	6	14	22	31	28	18	12	6	
	5	1	3	6	7	6	4	2	1	
	6	...	...	1	1	1	...	...	+12	
		·0551	·0692	·0808	·0679	·0427	·0335	·0169	·0072	= ·3733
STEM	1	·0462	·0285	·0165	·0091	·0030	·0010	·0003	...	
	2	355	355	296	223	134	64	19	4	
	3	166	177	180	164	118	80	41	12	
	4	34	58	68	71	53	33	14	7	
	5	4	10	16	17	12	7	4	+6	
	6	...	...	1	1	...	...	...	...	
		·1021	·0885	·0726	·0567	·0347	·0194	·0081	·0029	= ·3850
										Sum = ·7583

[Let V

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Let V = 12·174. Mult. by 224 = 169·86 = ϕS.

$V^{1\cdot7}$ = log.	1·84523	
S = „	4·45117	
f = „	$\bar{2}$·10170	
	4·39810	= 25010 = r_1.
$V^{3\cdot7}$ = log.	4·01609	
ϕS = „	2·23009	
C = „	$\bar{2}$·20041	
	4·44659	= 27960 = r_2.
		52970 = R in pounds nearly.
R = log.	4·72403	
V = „	1·08543	
h = „	$\bar{3}$·65450	
	3·46396	= 2910 = I. H. P. for V, 12·174.

Value of Constants.
f = log. $\bar{2}$·10170
C = „ $\bar{2}$·20041
n = 380
h = log. $\bar{3}$·65450

From trial I. H. P. = 2867

\+ 43· = Diff.

In conclusion, I have to beg you to overlook any incompleteness in this Paper, and I regret that I have not the results of more vessels to lay before you; but I hope to continue the study of this subject, and shall be happy to communicate the results at some future Meeting.

DISCUSSION.

Mr. C. W. Merrifield, F.R.S.: I rise to make a few observations upon this most important Paper. It is, of course, impossible adequately to discuss this subject; and it would not be doing Mr. Thornycroft justice were we to attempt it. I look with the greatest interest upon such formulæ, even though they are empirical. But I take this not to be entirely empirical, for I understood Mr. Thornycroft to say that the constants and the co-efficients of his equation were derived from the flow of water in pipes. I believe his formula is an empirical formula derived from the coincidence of the formula with the observed facts. I have one observation upon it, which is rather by way of making enquiry than finding fault. But this point occurs to me—I find in Mr. Thornycroft's Table there are seventeen distinct experiments, of which seven only appear to be calculated out in their completeness, so as to be capable of being made use of in

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the formulæ. When I come to count the different constants, and the different numerical values of the function, I find four constants, as h, f, n, and C, which for anything the formula shews, are arbitrary, and to be determined by experiments. I also find that altogether there are eight different numerical constants included in the formulæ. These are not all independent, because there are several mixed up together. But still there remain at the end of the chapter, at least six independent constants, some of them as multipliers, and some of them as indices. If you take six or seven experiments, it is easy to write down a formula of six or seven terms, each of them with arbitrary constants; and by equating the formula to the particular values, you can, by elimination, obtain definite values to these constants in such a way, that the formula shall meet every one of the small number of observed facts. I hope Mr. Thornycroft will be able to tell us—as no doubt he will—that although he has only thought proper to bring forward these six or seven calculated cases to-night, those are, by no means, all he intends to bring before us, because otherwise that constitutes a great difficulty in a subject of great importance. We know very well that a life annuity table can be generally represented with considerable accuracy by almost any arbitrary equation with constants. The late Mr. Gompertz showed that by a particular arrangement of the terms of an equation, the value of human life could be expressed in an equation involving only three constants over a large table; and there are few considerable tables in which it could not be represented by four constants, and there is scarcely any restriction if you are allowed to use five or six. That point about the number of constants is one which I certainly think requires some explanation, though I do not think it requires anything more. Seeing that the formula is easily applied, I think if we get any reasonable explanation of it, that will not at all detract from the value of the formula; but it alters very much its theoretical aspect.

Mr. THORNYCROFT: I may mention that I have retained the present formula in this form, because by doing so I am able to explain the different parts more easily; but it is possible, I think, to reduce the number of constants to even less than Mr. Merrifield has proposed. I would, however, remark that some of the constants may be eliminated at once, if we take vessels of the same length. For instance, take these terms out: $\frac{3n}{2n+l}$ and the second part of the resistance $\frac{n^3+3}{l^3+3}$, when the length of the vessels is considered equal, or nearly equal; in fact, in vessels not varying very much in length from n, the value of those factors is so nearly one, that the result is very little altered. I may point out that in this formula there is one merit which I lay claim to with regard to it,—namely, that in vessels of various bluffness, the calculated line nearly follows the several points in the actual trials given. With regard to the few experiments which I have now been able to lay before you, I would say that I shall be happy to calculate, as soon as possible, the results which any trials might give that are now being made. But the reason I have given so few trials is because although in all the published tables many useful parts of the data are given, yet it is very difficult to get all the necessary data, and the lines of the vessels, which, of course, are essential for these calculations. If any Gentleman possessing all the data required would kindly send them to me, I should esteem it a very great favour.

Mr. ROBERT RAWSON: There are several Gentlemen around me who, with myself, cannot understand the symbols represented in the formula. I have no doubt that those symbols admit of easy explanation; and, as the subject of resistance is a very important one, I think it would be attended with advantage if we understood how, for instance, the 1·7 and the 3·7 were obtained: and whether general symbols were used in those places, and the numbers determined by particular experiments.

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Mr. CHARLES LAMPORT: I apprehend that the number of constants which Mr. Thornycroft has put before us are precisely those points which it is so essential for naval architects to understand, and as to which we have, in the present state of our scientific knowledge, literally no data upon which we can rely. I think I am justified in calling the attention of the Meeting now particularly to the subject, because I think, Sir, as you were present at our opening Meeting, it will be in your recollection that when I was speaking to a point as to the action of the Council which was then under discussion, the President referred me to this very matter with reference to the resistance of fluids. If we are to find out a considerable number of constants, I think Mr. Thornycroft comes before us very much like the great mathematician and engineer, Archimedes, when he said, "Give me a fulcrum and I will move the world." Mr. Thornycroft says, "Ascertain for me eight constants, and I will tell you the result of the speed of "your ship." These constants are the very things we require. What I was going to suggest as the value of the collected action of the Council of this Institution, and its associated action, is simply that they should urge upon the Government, or some body (or do it themselves) the necessity of making some reliable experiments upon the forms of ships in order to ascertain these important points with regard to the constants. I believe the only reliable data which we have as naval architects are derived from some very elaborate and valuable experiments made by the late Colonel Beaufoy. Those experiments are of very little value to sea-going vessels. They were made with substances, shapes, forms, and masses 8 feet below the surface of the water. They are, therefore, provided in no degree for that very essential purpose—one of the most valuable essentials in the action of the form of a ship on the particles of water through which it moves, namely, the power and facility with which they can come to the surface, in order to diffuse themselves. I apprehend, with regard to any vessel passing along through the water, displacing a certain amount of water before it, and that same water filling in behind it, the whole of the amount displaced, and the whole of the mass of disturbance must rise to the surface and diffuse itself before the whole of the force is expended which moves the vessel through the water. I say, again, that we have no reliable data; and Mr. Thornycroft cannot ascertain his constants until the Council of this Institution uses its influence with some body sufficiently powerful and wealthy to undertake this, in order that we may have as architects and nautical men, some reliable data by which these constants can be satisfactorily ascertained. Therefore, if I am out of order now, in bringing my recommendation before such Members of Council as are present, I plead leave and license to say that I did forego the Discussion on this question at our opening Meeting, in order that it might be brought forward and discussed on the present occasion. I take this opportunity most earnestly to urge upon the Members of the Council that the time has now come for them to do something in their collective capacity in aid of the individual efforts which one and all have been making in order to carry forward our knowledge on this most important subject. I do not know whether any Member of the Council present would venture to make any statement, or give any assurance with reference to this subject; but if they fail to do that, then to-morrow, before we separate, I shall venture to intrude myself so far upon the Meeting as to move a Resolution that this subject should be brought strongly before the Council.

Mr. MERRIFIELD: I can say something which may perhaps go some way to satisfy Mr. Lamport as to the thing which he wishes done. I have the honour to be one of the Committee of the British Association to enquire into the Propulsion, Stability and Behaviour of Ships—not the Steam-ship Performance Committee, which Mr. Scott Russell has been employed upon. It was urged upon me, in considering the steps necessary to be taken, that the first thing was to prepare a digest

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of the existing literature on the subject—that digest is now in course of preparation by a clerk, acting under my instructions. That, probably, is the first step. The British Association being at work in that direction, with the ultimate intention, on their part, of going to the Government as soon as they have determined what experiments it will be advisable to perform, probably it would be premature and undesirable on the part of this Institution to take any decided action. I do not wish to burke discussion, but merely wish to give that explanation.

Mr. LAMPORT: I confess that I am somewhat surprised that our Honorary Secretary should have made the observations he has; I should have thought that he would have been one of the most jealous, for the honour of this Institution, that it should not allow a matter of this importance, identified as it is with this Institution, and forming, I may say, its very means of livelihood, to pass from our hands to another body. I say, even although the British Association are at work, let the Council of this Institution do something to urge on, and give a direction to this most important subject. It seems to me that the Council ought to be the first body to whom the British Association should have applied, in order to obtain hints as to what was best to be done, and the best mode of doing it.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): I would beg leave to answer this question in the first instance. As far as the Motion goes, it is all very well for any Member to get up and say that the Council are to do this, or the Council are to do that, or the other. We must have willing hands to obey. We have no power. We can only get volunteers; and as, in the programme of the arrangements for next year, it is proposed to put down certain points upon which it would be advisable to obtain Papers, the only way in which the Council can meet that question is to put the request that you have made on the Paper; and if other Members of the Institution will kindly send in Papers of a similar description, it will very much facilitate the labours of the Council on the 14th of April; and very much assist them in forming and drawing up the table of different subjects, which it is proposed to lay before the Institution, and invite persons to reply to. But as regards the British Association, I may state that I also belong to the same section as my friend Mr. Merrifield; and I believe that when Members of the British Association, and the vast talent which is collected there, voluntarily enter into committees of themselves to carry out a particular object, they can carry it out far better than we can do it here.

Mr. MERRIFIELD: In stating what I have, I did not wish at all to burke the action of this Society; and especially did I not wish to introduce any comparison between the British Association and ourselves. All I desired to explain was that the British Association thought the first thing was to get together a digest of what information we already possessed upon the subject, and it was with reference to the preparation of that digest, and not with reference to the separate action of this Institution, that I wished to speak.

Mr. JOHN SCOTT RUSSELL, F.R.S.: I cannot help thinking it is a very natural, right, and proper thing that the Members of this Society should feel and express a very strong desire to have better data for their professional guidance. It is quite true that the British Association has done a great deal. It is quite true that they have probably done more than anybody else; but I am bound to confess, as a Member of a certain Committee which was called the "Steam-ship Performance Committee," for the purpose of collecting valuable information upon this subject, that we have made an enormous collection of data

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which, when threshed out, have yielded a great deal of chaff, and very little corn. Now I will speak, not as a member of that Committee, but as an individual on that Committee. We organised for a long series of years returns of performances of steam ships, which returns were never very accurately made upon very accurate data. I think we may say the coals were not measured as they were put into the furnaces; I think we may say that the water which evaporated was not measured; I think we may say that the indicated horse-power was very rarely taken; I think we may say that we did not know whether the vessel's sails were doing much or little, or how much they were doing; and when I came to the conclusion of this mass of experiments, although I did my best to thresh and hammer away at them in order to get as much valuable corn out of the mixture as possible, I tell you that there were twenty bushels of chaff for a tenth part of a bushel of good corn. Now there was one thing which the British Association did not do, and I hope we may be strong enough to do it. I was one of a deputation who went up from the British Association (this very Steam Committee) to my Lords of the Admiralty, and we begged with all our might, and all our force, and all the energy, and power, and weight of this British Association, that the Admiralty would assist us in getting one single exact experiment, with one single, carefully measured ship, of which we should be able to say her resistance to going through the water is so many pounds. But my Lords of the Admiralty did not do it. I think that that is very encouraging for us to leave it alone, and leave it in the hands of the British Association.

Mr. LAMPORT: When was that?

Mr. SCOTT RUSSELL: A few years ago. We, of the British Association, are extremely willing to work, but the Admiralty is too many for us. Here we have many Members connected with the Admiralty who are Members of this Institution, and I think that this Meeting would do extremely well to let it be understood by the Council at their next Meeting that the Members are extremely anxious to beg for investigation, to furnish data for accurate ship construction, and they think there is a body called the "Admiralty" who are perhaps in a better position to give us those data than anybody else, and that, therefore, it is our very humble prayer that they will give us one or two perfectly accurate and reliable experiments on the resistance of ships. Gentlemen, that is very easy, and all those discrepancies between red lines and green, that is to say, between what the ships ought to have done, and did not do, could be removed by one or two little experiments which the Gentlemen of the Admiralty could easily give us. The following are the experiments: Give us one ship of which we know the shape thoroughly, and give us that ship in two states: First, when she is launched in the water without any machinery in her, but trimmed to some nice agreeable line that we shall settle, and in that state let that ship be dragged through the water by another ship with a rope upon which there is a dynamometer; we shall then know how much resistance the ship offers to being dragged through the water. Secondly, let that ship when all her machinery is on board, and when she is in the best state for being tried on her lightest draught of water, be a second time dragged through the water by one steamer, and if one is not strong enough let two go together to drag her as fast as she can be dragged, with the dynamometer, and let us know what her resistance is at that draught of water. Again, let her be laden to her deepest draught of water, and let her be dragged a third time through the water. I do not think that would cost a great deal of money, and if those three simple experiments were made, and handed to us, and put upon the black board, we should leave this room a great deal wiser men than we came into it. It seems to me that is a very modest proposition, not difficult to carry into effect, and one which would enormously advance the science of naval architecture.

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The CHAIRMAN: I do not appear here as the champion of the Admiralty, but I must say that I suspect that Mr. Scott Russell's co-efficient was not an effectual man. I have had to apply to the Admiralty personally, and as one of the Committee sent from the British Association, and I must say, although I am supposed to be a strong Conservative, that from the present Admiralty I have received every assistance, and infinitely more assistance than ever I expected to obtain from them; and I believe that if the men whom you select to go to the Admiralty are naval men—one of your body, who can make the Admiralty understand clearly and easily what it is that is required, they will grant anything in reason.

Mr. SCOTT RUSSELL: I beg to state that it was not the present Admiralty, but it was a past Admiralty. I may state further that one of the gentlemen who went up with us was himself, very shortly afterwards, a Lord of the Admiralty—therefore we took influence; another of them was a late Lord of the Admiralty—therefore we took past influence,—so that we took with us both past and future influence; and I do not think we could do much better now.

Mr. LAMPORT: I think, after the invitation which Mr. Scott Russell has given to independent Members of this Institution, that I shall not be stepping out of my place if I give notice to-night, that I, to-morrow, at the close of the Meeting, will move a Resolution—that our Council be requested to take such action, which I would rather have seen they had self-acting power to do without any such intimation. I will also combine with it the suggestion I made in the opening, namely, that we should have some reliable data also given as to the compound strains brought to bear on iron masts. I think if we, who are after all the greatest shipbuilding nation in the world, and perhaps, the most ignorant of data, have these two subjects thoroughly and properly gone into and investigated, and reliable data laid before us, we shall be able to propel our ships more safely, and sail them more efficiently than we have hitherto done, and we shall know better what the hulls can do.

The CHAIRMAN: Let the Paper define, if you please, what it is you want.

Mr. LAMPORT: It will be in the form of a resolution.

The CHAIRMAN: The resolution will be of no use unless you define what you wish the Government to do.

Mr. LAMPORT: I will adopt your suggestion, Sir, and to-morrow I will submit a resolution which will define what I consider necessary to be done, embodying what Mr. Scott Russell has so ably put before us.

Mr. SCOTT RUSSELL: I must say that we should not pay sufficient respect to the admirable Paper which we have heard, if we did not look a little at the very important conclusions which one may draw from it. There is, in my opinion, a very important conclusion to be deduced from it, namely, that there is a great deviation indicated there from the usual law of the square of the velocity, or the indicated power as the cube of the velocity. I will only call attention to this fact, that indicated horse-power is a very troublesome, and I fear fallacious, criterion of the resistance of ships, for this reason: it is a criterion of the resistance of the engine; it is a criterion of the resistance of the propeller; it is a criterion of the resistance of the ship; but of all the three muddled together, and which is which, and how much of one belongs to the ship, how much to the propeller, and how much to the engine, nobody knows. Therefore the reader of this Paper has been obliged to grope in the dark; and with regard to those very ugly figures which are upon No. 1 Formula (and they are very ugly, because instead

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of V^2, we see $V^{2\cdot7}$) I am quite sure that nobody will say, sooner than the author himself, that it was against his will that he introduced such a power as 3·7. I am sure he could not help it, but the complication of the problem in this manner is a result extremely to be deplored. I beg, however, as far as I may, to explain one difficulty which appears to me to shew itself pretty plainly in these experiments. I will just mention what has grown out of former experiments. Out of former experiments this may be, I think, taken for granted. Suppose this line (describing it) truly represents the resistance of a ship; and suppose that line (describing another) is not the horse-power but the square of the velocity. I think it is an established law, that there is a certain velocity, which I will call the velocity belonging to a particular ship, and that whenever that ship exceeds that particular velocity, the curve of resistance is much higher than the line of the square, and that when it is below that velocity, it either resolves itself again into the line of the square or it crosses below it. I may take that as almost a universal fact, and it is a fact easily explicable. I will give one notorious instance of it without explaining. Suppose *this* was the velocity due to a given horse-power, and *that* the velocity due to the propelling force of another horse-power, or double the horse-power; then we all know there is a certain velocity that double the horse-power ought to give. We all know that engines of double the horse-power have been put into many ships without sensibly increasing their velocity, and half the boilers have been taken out of many ships with scarcely any diminution in the velocity; therefore I say it is most desirable, in any analysis which is given of the performance of a ship, first to find out what is the velocity for which the particular ship has been built; because every ship ought to be built, and is built, for some velocity. If she is well built for a given velocity, you will find the resistance increases rapidly if driven at a higher velocity, and diminishes if driven below her velocity. In any analysis that the writer of this Paper should make in future, with regard to the resistance of vessels, I think it would be very interesting to us, and might be very useful, if this point were carefully adverted to in the experiments. No experiments can be more useful than careful analysis and experiments of that kind. I think we must not attribute any fault to the author, but assume that his formula is neither so simple or so beautiful as we should like to see it for our purposes, in consequence of the inevitable mixture of heterogeneous decimals.

Mr. Lewis Olrick: I only desire to ask one question, as the indicated horse-power has been condemned by Mr. Scott Russell as being very bad, I should like to know which horse-power he prefers, for I think nominal horse-power is worse.

Mr. Scott Russell: I quite agree; it is ten times worse.

Mr. Olrick: I confess it is killing me by inches; and the actual horse-power you can only get by applying a dynamometer, but my Lords of the Admiralty would never admit of that.

The Chairman: Gentlemen, I think our thanks are due to every Member who produces a Paper here, and it is evident that this Paper, although it has not succeeded to the extent the Author might have wished, has been productive of a monstrous deal of reasoning, and it may also happily be productive of a great amount of good hereafter. I think that our best thanks are due to the Author for his contribution.

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ON THE PRESERVATION OF LIFE AT SEA BY LIFE BUOYS AND RAFTS.*

By Staff-Commander W. S. Bourchier, R.N.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; Vice-Admiral Sir Edward Belcher, K.C.B., Vice-President, in the Chair.]

Without attempting to draw upon your feelings by a statement of the fearful loss of life at sea annually by drowning, I shall proceed at once to the subject of my Paper, "On the Preservation of Life at Sea by Life Buoys and Rafts."

First, as to life buoys:—This improved life buoy (marked D in sketch) consists of an air-tight oval thin metal casing, about 16 inches deep and 6 inches across, forming a double cylinder, and having a central space of 18 inches by 16 inches open from top to bottom, for the reception of the person or valuables to be saved. The interior of this casing is divided into two parts by a partition of metal, which is about 14 inches from the top (giving a capacity of about 3½ cubic feet), and leaves a space of 2 inches, which is to be used as a reservoir of fresh water by the person saved from drowning, in the event of his being compelled to remain adrift from his ship by reason of bad weather, fog, &c. This water space has two tubes leading to the top of the buoy, which are fitted with india-rubber nozzles or mouth-pieces.

The air-tight casing or floating power is sheathed, or covered with wood battens, tongued together to afford protection against the stem of a boat or a boat-hook, used in picking up the buoy; also to prevent the metal being bulged if it strikes the side of the ship in hoisting. This casing, which may be made in one or more compartments, and of any suitable metal, is enclosed in an open framework of iron or steel, connected by rivets, having a grating or small platform at the bottom on which the man stands. This grating is about 3 feet from the top of the buoy, thereby leaving a man's vital organs out of the water.

This apparatus is further provided with two stationary hollow tubes or sockets, about 1¾ inches in diameter, passing from top to bottom, each containing a signal staff for the

* Received 17th March, 1869.

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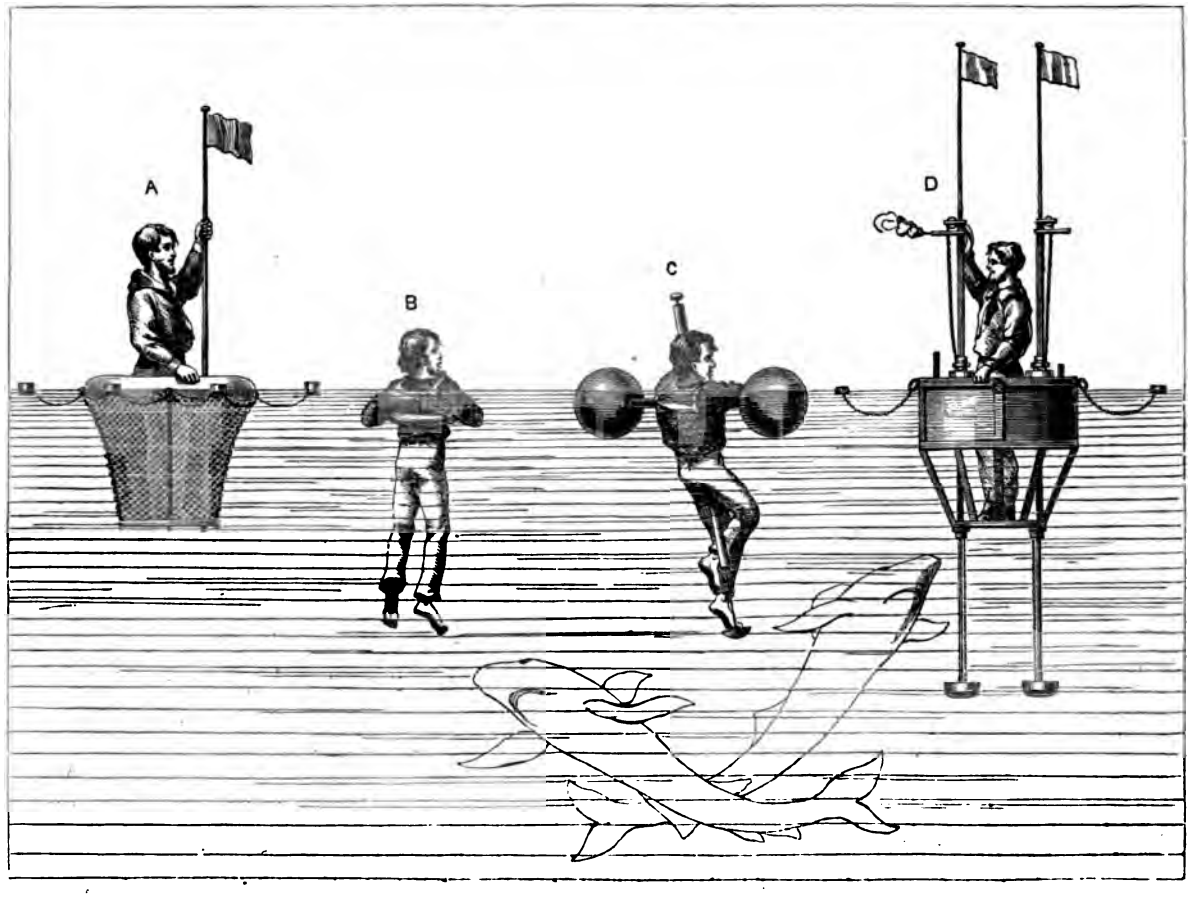
purpose of indicating the position of the apparatus or buoy to the man in the water, and to facilitate its recovery by the ship to which it belongs; also for attracting the notice of a passing vessel, should it be lost. Each signal staff is telescopic, being formed in two or more parts or sections, fitting the one in the other, the whole being contained in the stationary socket before mentioned. The signal staff is automatically raised out of its socket on the buoy, being "let go" by means of a weighted rod sliding in the stationary socket. To these telescopic masts or staffs are also attached port-fires or fuzes, to serve as signal lights—one being ignited by the action of "letting-go," while the other is at the service of the man in the buoy, to shew his position in a dark night.



NOTE.—The above sketch represents:

A.—Patent Cylindrical Ring and Platform Buoy, carrying one mast, with one light and flag, capable of supporting four men.

B.—Common Cork Ring Buoy, used in the navy and mercantile marine.

C.—Life Buoy invented by Lieutenant Cooke, R.N., in 1811, carrying one fuze or light, used by ships of war now.

D.—Patent Telescopic Two-Mast Buoy, carrying two or more fuzes or lights, reservoir of fresh water, &c., and capable of supporting five or more men.

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The first or port-fire section of the signal staff, is raised out of the socket by means of chain, or a copper wire rope, one end of which is secured to the lower part of the weighted or ballast rod; and passing over a sheave fitted to upper part of stationary tube, is attached to lower part of port-fire section, working in a slot or groove cut in stationary tube.

The upper or flag section of the signal staff is raised in a similar manner, one end of the cord being secured to the upper end of stationary tube; and passing over a sheave fitted in upper part of (first or) port-fire section, is attached to lower end of flag section.

The flag attached to this section or tube is nearly 7 feet from the water. The upper part of the buoy floats 6 inches, and when a man is in it, about 2½ inches out of the water. The outside size of the buoy, made of an oval shape, is about 32 inches by 30 inches by 36 inches deep, tapering from 18 inches from the top, so that the platform or grating is about 16 inches by 15 inches.

The arrangements for suspending and letting go this apparatus (which may be hoisted by any suitable tackle) are extremely simple. They consist of two hollow tubes, as davits, projecting horizontally from the ship's stern quarter, or under the bridge ends; a sliding bolt in each davit taking into an eye or loop on the sides of the buoy, next the telescopic masts (received in a slot on the under and outer end of each davit), which is thus securely attached. A cap is fitted to rods between the davits above each signal staff, to prevent the latter rising into position, when the buoy is suspended at the davits. The buoy is detached by withdrawing the bolts before mentioned, which are connected inboard by a bar, having a hook in the centre, over which the trigger line for firing the fuze is looped; thus the action of firing and "letting go" is simultaneous. If the port-fire is not to be ignited, the trigger line is detached from the hook previous to "letting "go" the buoy; the line remaining pendant from the port-fire pan, so that the means of igniting the same always remains at the command of the person in the buoy.

Corks or other floats are attached to the upper rim of the iron frame work of the buoy, by cords of sufficient length to go round a man's body, so as to afford a means of support in the water for several persons at a time.

The cylindrical ring and platform buoy, of which I exhibit a model, and which is marked A in the illustration, has been designed with a view of superseding the present inefficient cork ring life buoy, and it effectually carries out the principle involved in this system of saving life at sea:—that a man in the water, on reaching any life buoy, ought to be entirely relieved from the necessity of any further physical exertion, and should feel himself as safe as in a boat—nay, safer, for a boat can capsize, and our life buoys cannot. It will be almost unnecessary to shew that a man is safe from the attack of sharks in this cylindrical ring and platform buoy; and, although this buoy is not so

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efficient as the telescopic two-mast buoy, it must be seen that it is vastly more so than the ordinary cork ring life buoy used in the navy and mercantile marine. These cylindrical ring and platform buoys may be used in veering a line astern; and the confidence with which one or more men may be drifted on shore from a wrecked ship should render it worthy of notice to all shipowners.

Much more might be advanced in favour of this cylindrical ring and platform buoy in regard to cheapness, and also the different materials of which it may be manufactured; but time and space do not permit my going further into this part of the subject.

In pointing out the advantages of the buoy marked D, I must first call attention to the fact that a man must be much safer when standing up inside this life preserving apparatus, with his vital organs out of the water, than he possibly can be clinging on either to the life buoy at present used in the navy or the circular ring used in the mercantile marine.

The advantages of this life preserving apparatus are:—

Its great facility in working and general utility, particularly to exhausted men, not requiring the least physical strength in retaining their hold or position.

That it is perfectly *impossible* to hang or miss fire, when ordered to be let go.

That the action of "letting go" and fire is both instantaneous and simultaneous.

That it is capable of supporting a boat's crew by holding on the floating brackets outside.

That it carries sufficient fresh water (a small quantity of provisions may be, if advisable, stowed in this apparatus) to sustain life for several days, should the man overboard be lost sight of in the night, or in a fog; or the weather be too heavy to enable the ship to pick him up.

That in the event of a man in this buoy losing his ship altogether, it affords very great additional chance of saving his life, from the combined facts of his having *water to drink* for several days; *signal fire* to use at night; and two *signal flags*, nearly 7 feet above the level of the sea, always flying, for the purpose of attracting the attention of any passing ship.

That it affords the most complete protection against the attacks of sharks, &c.

That it can be hoisted up without lowering a boat, the tackle with span being lowered over; the occupant hauling down the masts, securing the stop chains, hooking it on, then hoist away both man and buoy. At the order "high enough," push in the slip bolts; the buoy is thus permanently secured, and all ready for letting go instantly, without sending a man outside the taffrail, or lowering a boat.

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That in the event of total loss of a ship (whether boats could live or not), all the ship's papers, chronometers, &c., and valuables, to the weight of about 200 pounds, might be stowed in each buoy, and sent adrift, when it must (sooner or later) be picked up by some passing ship, and the contents recovered by the lost ship's owners or underwriters.

That it need not, of necessity, be fitted to "hoist up" and "let go" in merchant ships, as in men-of-war; but may be lashed under the stern, or carried in one of the quarter boats, and thrown overboard when required.*

That in the event of a ship being wrecked on a lee shore, a man in this buoy could drift ashore with the end of a small line, and establish a communication between the ship and the shore; or, in case of obtaining communication by rocket apparatus, a man may be enabled to save children or women, from the fact of having both arms free, while standing up inside this life buoy.

In the event of a ship being wrecked on a shoal—such for instance as the Goodwin—and so heavy a sea running as to render it impossible for a life boat to get near enough to take the crew in, the life boat may anchor to leeward, and communication may be made between the wreck and the boat by means of this buoy; and shipwrecked people will most certainly have a much better chance of being saved, when it is found (as it has been proved) that no physical effort is required to maintain a person's position inside the life buoy.

I now pass on to the life raft, which, as a novelty in naval science, and as affording the means of saving life when boats are stove, or cannot live in a heavy sea, is of great importance in case of shipwreck by collision, &c.

I propose to fit the skylights, deck seats, bridges, or roofs of deck houses of passenger ships, with air-tight compartments, somewhat similar to the life preserving apparatus before mentioned, and by a simple arrangement of chains and spring hooks to connect them together, and thus form one enormous and safe raft. Each compartment of this raft may have a quantity of fresh water always available, and if fitted with the telescopic masts, will have signal fires to use at night (these signal fires being always

* If it be considered undesirable, or inexpedient to carry these life buoys outside a vessel, from her gunwale being too low in the water, as is the case with yachts, small coasting craft, &c., thus rendering them liable to be swept away by a heavy sea,—I meet this objection by showing that they can be carried inboard, attached by the "letting-go" apparatus to the inner side of the gangway door, or other part of the bulwark, so that at a moment's notice, they can be swung out over the sea, and "let go" in an instant of time. The suspending and "letting-go" apparatus can be fitted so as to be shifted to any part of a ship, and in the event of going into dock, or lying alongside a wharf to coal or unload, it may be unshipped and taken inboard.

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kept in readiness may be used as a blue light, when in their places on board in the event of danger by collision), and two signal flags which when the raft is afloat will rise to a considerable height above the level of the sea.

It will be observed that no preparation is required to convert these seats and skylights into a raft.

The masts and water tanks are similar to those used in the life buoy, further description of them is therefore unnecessary.

The skylight seats may be constructed with pointed ends, so as to enable them to be propelled through the water by means of oars, or temporary sails attached to the telescopic masts.

To shew how much raft space may be realized, without taking up more room on the deck of a ship than ordinary seats and skylights, we will suppose a ship's upper deck to be fitted with one skylight and four deck seats, on this plan. The skylight is, say, 12 feet long, and 6 feet wide, having an aperture 9 feet long, and 3 feet wide, thus leaving the seats of skylight 18 inches high, and 18 inches broad. Then the four deck seats being each 12 feet long, 18 inches wide, and 18 inches high, will give altogether 175 cubic feet of enclosed air space, and 144 square feet of standing or sitting room, which would be more than sufficient for fifty persons. The lower part of aperture of skylights should be fitted with two broad flaps of large meshed wire netting, so as not to exclude light or air when used as a skylight, and which serves as a floor for standing on when floating in the water. They should also be fitted with outside moveable flaps to turn up, and secure when required as rafts.

These rafts always serving as necessary articles of ships' furniture may be made to substitute some of the expensive life boats which merchant ships, over a certain tonnage, are now compelled to carry. The fresh water spaces they contain may be used instead of lumbering the decks of small vessels with tanks, casks, &c., thus giving more room for working the ships, or for deck cargo.

I shall now conclude my remarks upon the Preservation of Life at Sea, by reading letters from two gentlemen, one a naval officer on the staff of the Commander-in-Chief at Sheerness, and the other a landsman, who have both had practical experience of the life buoy.

"Sheerness, 15th September, 1868.

"Sir,—In answer to your letter, I give you the following as the result of my "experience of your life buoy on Friday and Saturday last.

"Although I had never seen it in the water previous to the trial, yet, on swimming "to it, I was surprised to find the ease with which it could be got into.

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"So little exertion is required, that I believe a person nearly exhausted from "swimming or exposure, would have no difficulty in getting into it; and when inside, no "further physical exertion is necessary, as his feet rest on the bottom of the buoy, and "his arms and chest are clear of the water. Consequently, he feels immediate relief, "and soon recovers from his exhaustion, to find himself provided with fresh water in "sufficient quantity to enable him, in the event of being lost sight of from the ship, to "sustain life for several days.

"When standing up in the buoy with my feet on the bottom, a position of perfect "security, I found the upper half of my body was entirely clear of the water, thus "relieving the chest from pressure, which, after much exertion in the water, is a source "of great relief, and which the present life buoy in use in the Navy, which I tried on "the same day, and of which I had had previous experience, fails to give, as it leaves "the whole of the body immersed, and requiring physical exertion to retain hold of. A "man much exhausted on gaining it, is, unless assistance speedily arrives, soon compelled "by fatigue to quit his hold,—more especially when there is any sea, and waves are "constantly breaking over his head. Such cannot be the case in your buoy; where, once "inside, the man will find himself in perfect security both from fatigue and sharks—the "latter a very great consideration in seas where these monsters abound; and by adopting "a sitting posture in the bottom of the buoy, which I found could easily be done, his "head would, to some extent, be protected from the breaking of the seas.

"The late trial took place in calm water only; but from what I felt then of its "stability, I believe that it would answer equally well in rough weather, and I only "hope that should it ever be my misfortune to fall overboard at sea I may find one of "your life buoys near at hand, and not be obliged to trust to the one in general use at "present, which I look upon as but a poor relief to a man in danger of drowning.

"Believe me, yours faithfully,
(*Signed*) "FRED^K. NORTH."

The second letter:

"25, High-street, Sheerness,
"September 22nd, 1868.

"Sir,—In accordance with your request I send you a short report of my personal "experience in the trial I made for you in your life buoy, in the presence of the "Commissioners appointed by the Admiralty, on the 11th September last. As a "civilian, quite unacquainted with nautical affairs, I cannot, of course, venture to offer "an opinion upon its capabilities for actual service. I can only tell you how I myself "found it under the conditions in which I made trial of it.

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"On first essaying to get into it I was considerably surprised to find how easy a "matter this was; I had been prepared to experience at least as much difficulty as "getting into a boat, but to my astonishment I found I could slip in and out of it with "much the same ease and facility as I could step in and out of an ordinary carriage on "land. No man, unless in the last stage of exhaustion, need find the least difficulty in "entering the buoy, and even in this last case, he would not be worse off—thanks to the "life lines—than if he were clinging to the ordinary service pattern.

"After trying the new buoy in various ways, always with satisfactory results, we "were requested to institute a series of comparative experiments upon this, one of the "ordinary service buoys, and a circular one. My experience of this course of "experiments was as follows. The service pattern and the circular buoy, though they "furnish ample floating power for one or two men, are yet very deficient in two, by no "means unimportant particulars; first, when the swimmer has succeeded in reaching "them, there is still a demand upon his muscles to maintain his hold—rather a serious "matter in cold weather, especially if the immersion be prolonged; secondly, neither of "the old pattern buoys professes to do more than support the swimmer's body *in* the water, "and in consequence offers him no security against sharks, or the more certain, though "scarcely less deadly exhaustion of vital power that inevitably accompanies any "prolonged immersion in water. Whereas, the new buoy, when once the swimmer is "fairly on board, is as safe as a boat; nay safer, for it cannot sink or be capsized. And "for the second item, as the water comes only a little above the hips, the breathing and "digestive organs, and vital apparatus generally, are raised out of the water, and "therefore beyond the reach of its injurious action. This latter point especially "impressed itself upon my mind; because, when I tried the buoy for the last time, I was "rapidly becoming exhausted with my long stay in the water, and the sense of relief "upon getting into it was so immediate and perfect—such a contrast to the mere "muscular relief afforded by the other buoys—that it could not but make a strong "impression upon my mind.

"I have only to offer you my sincere good wishes for the success of your excellent "invention, and beg you to believe me,

"Yours faithfully,

(*Signed*) "FREDERICK WOOD."

I do not invite criticism on the models, they being rough ones, but they will, I think, sufficiently shew the object I have in view. I have now only to thank you for your kindness in listening so patiently to my poor endeavours to interest you in the Preservation of Life at Sea.

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DISCUSSION.

The Rev. Mr. DREW: I will make a few remarks upon the subject of preserving life at sea. It is one which does infinite credit to an Institution like this; and from what we have heard lately, and have seen in the public journals, we learn that both in the Royal Navy and the mercantile marine there is ample room for improvement. About a fortnight ago I wrote to one of the public papers on the subject, and have some slight acquaintance with the Lecturer of this evening, who kindly showed me his models. The "Casual Pauper," Mr. James Greenwood, told us the other day that the life buoy in common use in the merchant service, was, in nine cases out of ten, made of reeds, and when it was not made of reeds it was made of straw. He weighted three of these with a ten-pound weight. The first one, which was made of cork wood, floated four hours, and three of them went under water in three hours. Every merchant ship in the English mercantile marine, is, I believe, provided with that circular buoy; therefore I am justified in saying that nine-tenths of our merchant ships have no probability of saving the life of a man who goes overboard. In use, the position of the man if he succeeds in getting into a common round belt, is very unsatisfactory. He is certainly kept above water for as long as his muscles will enable him to hold on, but I see on one of the diagrams an ugly-looking shark who would certainly be an awkward customer for a man in an ordinary life buoy to deal with. Those who go to sea know that that is a thing which a sailor dreads more than anything else. He does not care about going overboard, and the hardship of having to swim, so much as the peril which he encounters from being exposed to sharks. I have been in places where I have seen sharks in shoals, and it would take the courage out of one enormously to feel that one had only that miserable piece of cork to depend upon. If you look at the Admiralty buoy it is, certainly, better than the cork buoy; but I never heard of its saving life under anything like difficulties. When it is calm weather it is possible to lower a boat and pick a man up in five minutes, where the man is sighted. It is certainly better than the cork buoy, but still one which is open to objection, and a person would not feel very comfortable if he had to trust his life to it. The other one shown in the diagram, though ugly, if it is anything like that which is described, certainly commends itself to my mind as a landsman, as being a certain means of saving life, which is of the greatest possible consequence. I do not see any reason why Her Majesty's Navy and the Lords of the Admiralty, who are so ready to give us information, as we are told, should not give us information with regard to the means they have of saving life at sea. The only answer they could give us, is, that we have got a couple of round balls, like cistern balls, connected with a rod of iron or wood, and if you do not like that we have nothing else. If a gentleman comes forward with a suggestion, I think he deserves the assistance of an Institution like this, and that assistance which naval officers generally are so ready to give with regard to any inventions which bear upon their own profession.

The CHAIRMAN (Vice-Admiral Sir Edward Belcher, K.C.B.): I have known Cook's life buoy, I think, now about fifty-four years. During the whole of my service, I may say that I never knew a man lost upon one of these buoys who had not been previously stunned or maimed. As an example of its utility, I may mention that one of my men at work in the main channels of the *Samarang*, going 12 knots, in 60° south latitude, fell overboard, and was struck by a very heavy sea indeed. It is rather an extraordinary

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thing for an officer, under those circumstances, to haul his wind and tack; but the *Samarang* was a ship that would do anything that she was told. We hauled our wind, tacked, and brought the life buoy under our lee. The man's arm was said to have been seen through the buoy; but when it came under our lee main channels, he was not to be found. No boat could have lived; and the only chance was that of making the ship perform the duty, and save the man. If the man had not been maimed or stunned by the blow of the sea, I am perfectly satisfied we should have saved him. I admire this buoy very much indeed, provided the man does not get hold of it in a rough sea, for I think it would ill-treat him very much before he got into it. If it was well covered with cork and canvas, so as to prevent the rough edges injuring him, I think it would be preferable. As to the circular belt—I forget the name of the gentleman,—he was a lieutenant in the Navy, who came to me (in 1847); but I told him at the time that cork, like any other wood, as well as the canvas covering, after it has remained a certain time over the side, exposed to bad weather, gets sodden; and if it were for three weeks exposed to a gale of wind, going round Cape Horn, or any such place, it would be of very little use. There is another point:—not only is there the difficulty of saving a man when he goes overboard, but there is the difficulty of finding him; and people do not seem to pay sufficient attention to guiding the boats that are to look after him. A man falls overboard, and the ship runs a mile or a mile and a half before the boats are lowered to pick him up; and those in the boats cannot possibly see the man struggling in the water. I had occasion, when some of our men were in difficulties among the ice, and we were surrounded with masses of considerable height, to direct the men; and while the parties were out on the ice looking after him, the idea suddenly suggested itself to me that, as we could see him from the ship, we could direct the people to him; and we did it thus. The man was out among pack-ice; those who were in search of him could not possibly find him; we suspended two flags in a line with the point where the man was seen; we then sent out a man with a flag attached to a boarding-pike, who moved on, keeping the two flags perfectly in line: it was easy then to point out where the man was, and he was saved. I think it only remains for us to thank the Author of this Paper for exhibiting this life buoy. If it does not succeed itself, it evidently, to my mind, is the nucleus of some other invention which may be improved upon; and I hope, when the Author appears before us next year, he will give us something additional—even if there was nothing else but a single bar across, for a man to get his feet upon, it would be a wonderful relief.

Staff-Commander BOURCHIER: The object that we have had in view, and the fact we wish particularly to establish is that a man must be safer with his vital organs out of the water, standing on a platform.

Captain JASPER H. SELWYN, R.N.: I should like to offer one word of remark upon the two systems. The one presents a great deal of ship-shape appearance and the other very little. I should not like to hang the one over the stern; for I should be certain that long before I came to use it it would be washed away. The other, I think, would remain there, and I should be sure it would be ready for use when it was required. Although the first one is very liable to be washed away, I do not say that it cannot be made in a different shape, so as to offer a longer oval, so to speak—in fact, more width and less projection from the stern; but I am afraid that our sailors, who are still, in spite of our iron-clads, rather proud of their ships, would not like to have too much projection, on account of the look of the thing. There would be a prejudice on the part of the sailors, which it would be wise of the inventor

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not to needlessly affront. I think we can say distinctly that the other is much more practical, though it does not offer so many advantages. It is not so compendious in giving the advantages, which people do not think so much of until they have been some time in the water.

Staff-Commander BOURCHIER: I have occasionally seen men overboard, and the first difficulty the man has is to see a life buoy. A man cannot see the Admiralty life buoy unless it is within a yard or two of his nose. The same reasoning holds good with the circular buoy. The object is to have it visible above the surface of the water, so that not only the man can see it, but the captain of the ship can see it likewise. If a man gets hold of our life buoy, and the captain of the ship does not see whether the man is in it or not, the man in the life buoy pulls the trigger line of the fuse; and then the captain would say, "I know that my man is safe, for he could not have pulled that trigger unless he "were in the life buoy," and then the boats would go and pick him up.

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ON COPPER SHEATHING FOR IRON SHIPS, CONSIDERED AT THE PRESENT STAGE OF OUR EXPERIENCE.*

By JOHN GRANTHAM, Esq., Mem. Council.

[Read at the Tenth Session of the Institution of Naval Architects, 20th March, 1869; the Right Hon. Sir J. S. PAKINGTON, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

IT would have been necessary, under other circumstances, to have offered some apology for bringing before the Meetings of this Institution a subject which has in various forms already engaged their attention; but many reasons have caused me to tax your patience by again asking you to allow it to come once more under your notice.

The subject itself is not attractive, and it requires some courage to present it before such a Society as this. The best argument that can be offered for its reconsideration is that, after many years of agitation, the principle now to be referred to is being largely adopted in Her Majesty's Navy, and the time which I have been so long and anxiously waiting for has arrived, when not only in the Navy, but in the larger vessels of the merchant service this system will probably receive the attention it deserves. A more important one for the advancement of ships of this class cannot be found; and we have only now to regret that the question of its practicability had not been set at rest many years ago, for in case of its success, of which I see every reasonable probability, many millions sterling might have been saved to this country. There has been no session of our Institution in which the question of the speed of vessels has not formed a conspicuous part—and the large sums expended to attain a constantly increasing speed in our ships of war indicate the importance attached to the subject—but follow these ships into actual service, and, if built of iron, a month has not elapsed before a sensible diminution of speed will be perceived, daily increasing until often our finest vessels are reduced to one-third their proper velocity. That it was not tried at an earlier period was very remarkable, when it is known that many of our most experienced men were fully conscious of the extent of the evil which it was intended to obviate: this remark applies

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not only to the nautical men, but to some of our most eminent shipbuilders, whose interests were so largely involved. We find that, even in speeches made in the House of Commons for several years past, two great evils in iron ships as applicable to the Navy were sufficient motives for continuing the construction of timber ships, a large fleet of which has been set afloat and hardly completed, when the magnitude of the mistake of attempting to apply engines of the highest power, and armour-plating, to such vessels becomes daily more apparent.

Happily, we are not called on now to give proofs of this tendency of iron ships to foul, or of the amount of injury sustained by it. We can afford to give up many things, if necessary, to attain that most important object, freedom from fouling—for instance, in sheathing an iron ship with wood to receive the copper, her beam is increased at least twelve inches. This, however, is not all loss, as her displacement is increased to a greater extent than the increase in her weight, so that she draws less water.

But when it is shown, as it can easily be, that the loss of power in an iron ship, by the foul condition of the hull, is frequently one-half, we see quite enough to induce us to overcome much more serious objections than those which have been brought against sheathing the ship with wood and copper.

The two great questions above alluded to were the tendency of iron ships to become foul, and their liability to be easily pierced when in contact with hard and sharp bodies; so great was even the latter evil, under certain circumstances, that it is said only one of the numerous iron vessels which accompanied the fleet to the Baltic, in the Russian War, escaped without having a hole knocked in her bottom. The plan which has been recommended, and which is now to be explained, for removing one of these evils, is happily well suited to remove or ameliorate the other evil. The application of a heavy timber sheathing to carry the copper, with which the vessels are to be covered, interposes between the ship and any hard substance with which she may come in contact, an efficient buffer, that will, no doubt, greatly relieve the danger of the plates being penetrated. A history of the leading questions upon which we have based our arguments in favour of this system may be interesting. The magnitude of the evil to iron ships by their tendency to foul became very apparent at least 30 years ago, and both practical men and our leading chemists eagerly sought for remedies; and every principle which has from that time to this been frequently brought forward as a remedy was, at the earliest stages, fully investigated; some trifling amelioration has been produced, but nothing which has ever been stamped by the public as an efficient cure has been discovered. Having witnessed these repeated failures, and seeing how much the introduction of large ocean steamers was retarded, I made many experiments to

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ascertain whether copper could be as safely employed as a sheathing for iron ships as it was for timber ones, and I became convinced that this could be done. I watched carefully the effect of the combination of copper and iron, and the means necessary to render their close proximity innocuous, and I saw that this was practicable. The application of copper to iron ships, with the intervention only of some adhesive and non-conducting substance, was practicable, but not efficient: the vessel taking the ground, or the most ordinary abrasion of the surface, would readily displace it, and serious results to the iron plates would be the consequence. I, therefore, determined to recommend the intervention of a timber sheathing, to which the copper could be nailed in the ordinary manner. My first difficulty was to devise a plan by which the timber could be attached to the ship with safety. Many attempts had been made in the early stages of iron shipbuilding to attach timber planking, bilge logs, and false keels externally to the iron shell, and the difficulty of making sound work was so frequently perceived that I did not venture on its adoption; the effect almost invariably produced was the loosening of the bolts which attached the wood, caused, as I believe, by the unequal action of the two materials when the ship laboured in the sea. Since my attention has been more closely drawn to this subject, another source from which many facts could be gleaned, has sprung up. About the time when I began to publish my views on this subject, Mr. Jordan, an eminent shipbuilder in Liverpool, built two ships upon a system now publicly known as the Composite ship: these are constructed in the following manner:—A complete framework of angle-iron is first produced, to which are added, externally, an iron sheer strake, garboard strake, and other longitudinal fastenings, and to these are added, in some cases, a system of diagonal trussing: a complete frame being thus prepared, timber planking is added, secured to the frame by bolts; these have generally been of iron, sometimes galvanized. Sometimes, also, Muntz's metal, and even copper, has been employed; if of iron, great care has been taken to preserve them from corrosion, but with only partial success. The galvanized bolts have corroded the most rapidly, and have been quite abandoned; copper bolts are being used, but not long enough to enable us to judge of the amount of injury to result to the iron framework of the ship; the expense of copper is also considerable.

But it is with iron bolts that we are most concerned, as the points to which we are leading have reference entirely to iron ships.

In a large number of composite ships, when only two or three years old, the bolts have been found to be seriously wasted, and considerable expense has been involved in replacing them, and so much alarm has been caused in Liverpool, where the system commenced, that not one more is being built. In other places they are still in great favour.

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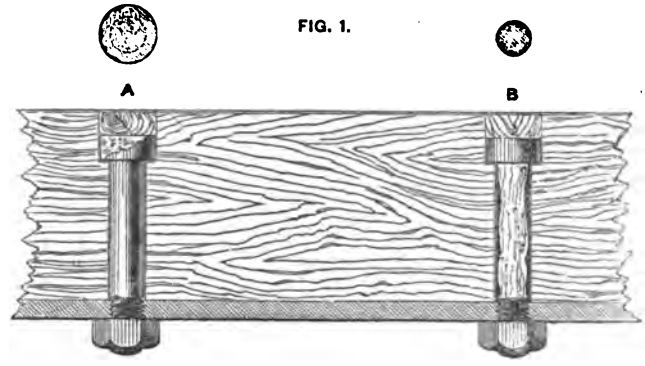
The woodcut, Fig. 1, represents two bolts as used to fasten the planks on to a composite ship, and illustrates the way in which the corrosion commences. Sometimes it commences with the head, as at A, and sometimes the body between the iron frame and the head is first attacked, as at B, and the head will remain sound. The probable reasons for this will be presently shown.

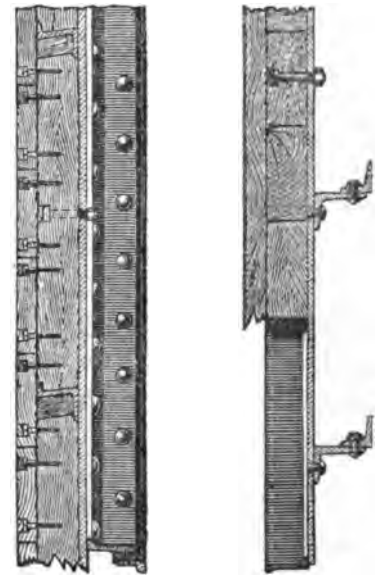
FIG. 1.



Some composite ships have had two sheathings of timber, and the system is said to have advantages. In either case, however, the vessel is finished outside by a sheathing of copper or other metal, as in timber ships.

The case of the composite ship here cited affords a good basis on which to work out the probable results to a ship built entirely of iron sheathed with wood, and coppered, which, in general terms, is the principle which I early sought to establish: the great difference being that, as in the composite ship the planking is secured to the iron work by bolts only, I substituted an external iron frame riveted to the plates, as in the woodcut, Fig. 2, so formed as to receive a sheathing of timber, and so firmly wedged as to be secured almost entirely without the use of bolts; on this inner planking is attached by brass screws a lighter sheathing of wood, to which the copper is nailed in the usual manner. Precautions would, of course, be taken to apply suitable coating between the planks, and the seams would be caulked, so as to render the work as sound as possible.

FIG. 2.



In addition to this, one other precaution would be necessary in order absolutely to avoid all possibility of a metallic contact; I proposed the substitution of brass stem and stern-posts for those made of iron.

The drawings now exhibited sufficiently explain the plan of fastening the timber planking; and but few further remarks are necessary by way of description, as nearly all present are partially acquainted with it. It is only necessary to say that, assuming it to be applied to a new ship, the inner frame would be reduced in weight in proportion as

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weight is added externally; but one great advantage results from this arrangement: if the principal internal framing be vertical, the external frame may be longitudinal; or if the main internal framing be longitudinal, then the external frame may be vertical; the effect of either plan is that both frames may be attached direct to the shell, and cross each other's path without either being cut into short lengths, as must be the case when both horizontal and vertical frames are attached on the inner side only.

The naval architect will, of course, modify this general description to suit his own taste or the requirements of his ship; it points, however, to one feature, namely, great simplicity of construction.

It will now be seen that the composite ship and the iron ship thus sheathed have many points in common: both are composed of iron frames and plates, both have a timber planking, and both are sheathed with copper. Upon one point, however, there is a striking difference between the two: the planking of the composite ship is necessarily secured to the iron work by bolts; in the system now described the security of the planking is made to depend principally on the external framing; bolts may be used, as shown in the drawings, but their explanation, under these circumstances, will be better given in another place.

Taking a backward glance, for a moment, at the history of composite ships, I believe I may assert that the following result has been invariably, more or less, perceived; the iron frames and plates have shown but slight tendency to corrosion: one of the two ships above alluded to, as built by Mr. Jordan nearly 18 years ago, was wrecked when about 10 years old, and it was discovered that the iron frames and plates were in excellent preservation, but the bolts were badly corroded. About two years since the second ship was seen by a friend of mine, in the Graving Dock at Calcutta, when several of her planks had been stripped off, and the same results were perceived. A large fleet of these ships has been built during the last few years, and every precaution has been taken to secure the bolts from corrosion, but, as above stated, with only partial success.

The serious question now arises, Why have the bolts almost invariably suffered, while the iron framework and plates have been preserved? The reason, in my opinion, is quite simple: to a structure made of a hard and incompressible material is attached a shell of a material soft and yielding; the motion given to the ship when labouring in the sea gives rise to an opposing action between these two ill-assorted substances; the bolts which unite them have to sustain the enormous strain thus produced; an imperceptible loosening then takes place, and, as the hole enlarges in the timber, water is gradually drawn into the space, and a constant change of water is the result: all this prejudicial

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action would be counteracted were the planking supported by the external frame above described; and the loosening or rubbing motion, between the wooden planking and the iron shell, would have no commencement in the latter case as in the former.

It is quite possible that the timber might become saturated with salt water, and the apprehension of this for a long time prevented us from attempting to adopt these systems of sheathing; but I believe the explanation given by Mr. Mallet, when discussing the merits of this question, will be found to be the true one. Speaking of the system of the external frame, he says, "But if the sea water should find its way in, the amount of "corrosion that could take place, unless there were a stream of water in and out, so as "constantly to renew the agents of corrosion, would be next to nothing. I have already "shown you that if a piece of iron be put into water already robbed of combined air, or "if you exclude the air from it, it will not corrode at all. Therefore, if water should get "in and lodge behind any one of these blocks of wood, unless it be perpetually renewed "by a stream in and a stream out, the water that has got in there will, after a short time, "have next to no power in the way of corrosion." It is only necessary to remind you that this "stream in and stream out" is the exact condition which we attribute to bolts, under the circumstances above described, and which, no doubt, Mr. Mallet would have taken as the explanation of their rapid corrosion.

The air which is found in combination with water is the agent by which corrosion is produced, and it does not require that the water should even be salt for oxidation to go on; but this is rendered specially dangerous when the process of oxidation is accelerated by the galvanic action of the copper and iron, together with the acid of the sea water. Rob the water of the agent of corrosion, oxygen, and the whole is harmless.

Referring again to the Drawing of the two bolts, and taking the first example, A, I suppose the rubbing action between the planks and the plates to be going on, the bolt gradually loosening, and a slight stream of water being drawn into the bolt hole, in this case finds its way first to the *head;* the oxidation then commences, and the small quantity of water being deprived of the combined air does no further harm, and if arrested in time, the body of the bolt may not have suffered at all. Or in the case of bolt B, the water may first find its way to the *body*, and there the oxygen, being taken up before it reaches the head, has become harmless, and if arrested in time, the body of the bolt will alone have suffered. In either case, however, if the process is allowed to go on, both the head and the body of the bolt will perish.

I respectfully offer these views in explanation of the serious facts above described; others may have sounder theories on the subject, and if so, it would add very much to the advancement of this great movement if more correct views were given.

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There are several instances of copper and other metallic bolts, as before stated, having been substituted for iron ones; but the change in material does not alter the amount of strain to which they are subjected or the tendency to become loose; and should we be able to prevent corrosion in the bolt, we should probably transfer the mischief of corrosion from the bolts to the frames.

Unwilling as I am to make any allusion to special plans adopted by others, it is impossible to avoid taking some notice of the plans now being carried out in the Navy. No less than five or six iron ships of the largest class are now being built with the intention of applying copper sheathing on a timber base; the ice is thus broken, and the system, unfortunately so long in abeyance, will now be put to the test.

The Chief Constructor has avowed that he has entered upon these plans reluctantly, but I foresee that we shall soon look back upon this event as an era of the highest importance in the history of iron shipbuilding. I say this although he is aware that I differ from him in that essential feature which I have been above discussing. The new ships are being sheathed on a plan almost identical with that which I have so long urged upon the Admiralty; the brass stem and stern-posts, the heavy inner sheathing of wood next the iron hull, and outer sheathing of lighter wood secured to the inner one by brass wood-screws, over which the sheathing of copper is to be applied,—in all these points the plans correspond; the mode of attaching the inner timber lining is the point on which the respective plans differ.

The attachment in the new ships is by bolts only, as adopted in the composite ship: the arguments for objecting to this system need not here be repeated; I consider them to be of equal force in both cases. The woodcut, Fig. 3, represents a portion of a

FIG. 3.

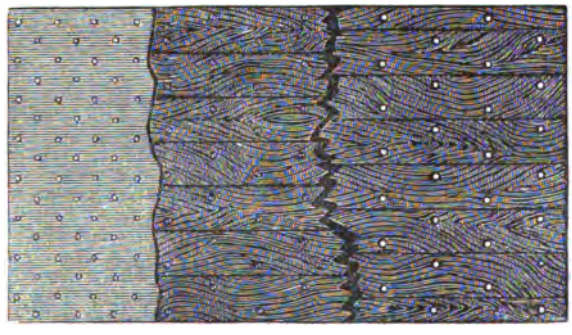
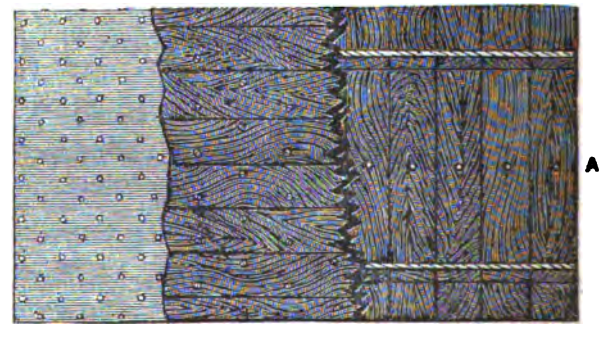


FIG. 4.



ship where the planking is secured by bolts, of which there may be from 20,000 to 40,000 in one vessel. Fig. 4 is the portion of a ship where the planks are secured principally by external framing, though, as before observed, a few bolts, as at A, may be introduced, if thought desirable, to draw the plank closer to the plates.

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The exact plan by which the details are carried out is, however, of much less importance (so long as the work is well executed) than the circumstance that iron ships are being sheathed with copper to prevent fouling. We may feel assured that the work is being well executed, and the evils above anticipated may, in such vessels, be long in showing themselves. Should it hereafter be seen that the plan of iron framing now described is superior to the simple attachment by bolts only, we shall at any rate have ample evidence as to the success, or otherwise, of applying copper to iron ships.

Before concluding this Paper, it is but fair to notice some of the objections which have been raised to the external frame: the expense is not one of these, as it is admitted that the cost is less than that of applying bolts: one defect that has been suggested is, that the inner planking will not be kept in such close contact with the iron as when bolts are used: I much doubt this; but, to meet the supposed defect, I have shown that I do not object to the application of a limited number of bolts, for the simple purpose of drawing the two bodies into closer contact, as represented in the drawing, my objection to bolts being of another character, that of allowing them to be the sole medium through which the enormous strains produced when the ship is working in the sea are to be sustained.

It has also been objected that, in extreme cases of injury arising from contact with rocks, the framework may be torn away, and the rivets broken, thus admitting the water: the liability to this, in my opinion, is much less than where bolts only are used. A heavy ship, beating violently upon the rocks, will destroy any work however strong; but there is one consolation, which is favourable to the plan of sheathing iron ships with copper, arising from the statement made by Mr. Mallet when discussing this subject a few years since at a public meeting: he made a calculation of the amount of injury which would be sustained by an iron ship under the circumstances of the wooden sheathing being violently torn away, and the copper being brought in contact with the iron. He adds, "I would merely say this much, that there certainly would be no such amount of "corrosion as to endanger the safety of the ship at sea before she could get home, or into "some port where the accident could be repaired. . . . . The fact is, that the "surfaces of both metals, when left to themselves in sea water, get coated more or less "with various insoluble sulphates, and other salts and oxides derived both from the iron "and from the sea water, which alter altogether the rate of corrosion that would "otherwise take place were chemical action quite unimpeded."

The arguments in favour of adopting some plan for obviating the fouling of iron ships, and the proofs that no such plans have met with sufficient success to make it practicable to employ iron ships of war on foreign stations need not here be repeated;

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the facts are everywhere avowed. There can be no subject of a practical character more worthy the attention of our Institution, and I trust it will receive that consideration its importance deserves.

On former occasions I have enlarged upon this question very much, and have attempted to shew that in all probability a ship like the *Warrior* would go as fast with at least half her power, if she were kept clean, as she would do with her present power when she becomes foul; that is, that really one half of her power is thrown away, and that she would be as serviceable a ship when long at sea, if kept clean, when only half the power was employed. I have thought it unnecessary to go into all the details, when all who are here are fully aware of the serious consequences which accrue to ships from fouling.

ON ZINC SHEATHING FOR SHIPS.*

By Benjamin Bell, Esq.

[Read at the Tenth Session of the Institution of Naval Architects, 20th March, 1869; the Right Hon. Sir John S. Pakington, Bart., M.P., G.C.B., D.C.L., President, in the Chair.]

The question of protecting the bottom of an iron ship from corrosion and fouling has always been one of the greatest interest; but during the last year or two my attention has been by special circumstances more particularly called to this subject.

We have been building at the Thames Iron Works two corvettes of 2,321 tons each,—the *Volage* and *Active*, just launched for our own Admiralty,—in which the object of keeping a clean bottom is sought to be attained by constructing, first, a complete iron hull, sheathing it with two thicknesses of wood; the first fastened with iron bolts screwed through the hull plates, the second fastened with copper screws into the first, then receiving the copper as in a wooden ship. Two iron-clad frigates, of nearly 4,000 tons each, have been ordered and are building on the same plan; and a larger corvette, the *Inconstant*, of 4,000 tons, has been built at Pembroke, on a plan differing somewhat in detail, but of the same character.

* Received 20th March, 1869.

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In the summer of 1867, the Thames Iron Works Company, in common with other leading shipbuilding firms, were invited by the Admiralty to submit competitive designs for an iron-clad ship of war, and, amongst other points, were especially asked to propose any plan which they could recommend, either for coppering or zincing them.

In the course of building the *Volage* and *Active*, I have been very strongly impressed by the great difficulties and enormous cost of producing a perfect work, of which the essential condition was the absolute insulation of the iron hull from the copper, and of maintaining that insulation throughout, under all contingencies and against all accidents. I can well appreciate the anxiety of the Chief Constructor, the designer of the ships, and his officers, that their object should, at least, in the beginning of the ship's life be obtained; and the anxiety, perhaps not less, which must arise from the consideration of the many contingencies that may hereafter defeat it, and bring together under water such deadly enemies as copper and iron. If I may venture to express an opinion, it would be, that in constructing, first, a complete iron vessel not only with iron frames, but entirely iron plated, and obtaining thereby the rigidity and freedom from working of an iron hull, the best and perhaps the only security is obtained; but all the money and pains which have been expended are liable, over a large extent of surface, and by a variety of causes, to be at once rendered useless.

The fact being well known that zinc bears to iron just the opposite relation of copper, and that galvanic action established between the two metals results in perfect protection to the iron, and a corresponding exfoliation of the zinc, it would certainly seem that in its application to an iron ship an escape from all these difficulties might be hoped.

I do not propose to go into the question of compositions; the foregoing facts are enough to shew that, in the opinion of the English Admiralty, no doubt the best judges of the matter, and the most deeply interested therein, no existing compositions really meet the difficulty of the fouling of an iron bottom; nor is there much prospect of success in this direction; but that we must resort to a metallic sheathing. It is, I think, accepted, that no smoothness of surface, no poisonous or electrical character of the composition, will keep off the barnacle, and that the only means of accomplishing this are the corrosion and exfoliation of the surface which, in parting with a portion of itself, parts company also with its parasites.

If zinc, when acted upon galvanically, will exfoliate as the copper does on a wooden ship, and if this exfoliation can be controlled and regulated to the proper point, it would then follow that we only want a feasible method of securing it under proper conditions for this galvanic action to the iron ship to supply this desideratum.

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I assume that the first of these points has been settled by decisive experiments; those made at Sheerness and Portsmouth at the instance of Mr. Daft, and all the experiments made by the French Government, which are not a few, give decisively this result, that the zinc corrodes and is kept clean, at the same time protecting the iron.

As to the second, I have learnt lately that for some years past in a large line of steamers sailing out of Liverpool, zinc has been used to protect the boilers and iron tubes, where surface condensation is practised, from being destroyed by the corrosive action of the water which has passed through the copper condensing tubes. The plan adopted has been to hang up in each stack of tubes a large piece of zinc suspended in the water, this is rapidly destroyed to such an extent that $\frac{1}{4}$ inch of zinc disappears in less than a month, while the boiler itself and the iron tubes are completely protected.

On wooden ships, zinc, as a sheathing, has long been used as a cheap substitute for copper for the sake of protection against worms, and for comparative cleanliness; here there is little or no contact with iron, a very small amount of galvanic action, and consequently a small exfoliation of the zinc, which lasts for years almost uninjured. It does not, therefore, keep the bottom as clean and bright as copper; but it approximates thereto, pays for its use, is better even thus than nothing, and better than any painted bottom.

It appears to be the irresistible conclusion from facts like these that we have the exfoliation of the zinc completely under control, from the minimum on the wooden ship with little iron contact, to the maximum in the water and steam in an iron boiler; and this admitted, that we have only to get a combination which will make the zinc exfoliate at the same rate as the copper on a wooden ship, to obtain the same result of a clean bottom.

We have then to attach the zinc to the iron bottom, and to do so under suitable conditions, for regulating the galvanic action; and it is with this proposition that I have attempted to deal.

Two methods have been proposed and experimented upon, both of which go upon the supposition (in which I entirely concur) that, in some form or other, wood must be used as an intermediary between the iron and the zinc; no plan of attaching it by cement or adhesive compounds has given the smallest hope of success.

One plan—that of Mr. Lungley—has been to coat the iron ship completely with wood, secured by channel iron riveted to the ship's side, and then fastening the zinc as

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the sheets of copper are fastened to an ordinary ship: the other—that of Mr. Daft—has been to leave a small opening between all the longitudinal and vertical edges of the plates, filling in this with a tongue of compressed wood, and fitting sheets of zinc of such size that their edges exactly coincide with these tongues, and fastening them thereto with nails.

In the former case, as the conditions appear almost identical with those of a wooden ship, and the galvanic action a minimum, much difference of result could hardly be anticipated, and, so far as I am informed, such was the result of an experiment which has been made.

To the latter, the objections have been urged that a fastening only by the edges of the zinc sheets to so small a tongue of wood, could hardly be depended upon, and if supplemented by fastenings into the central parts of the iron plates, great cost would be involved, while it was not desirable in view of structural strength to separate the butt edges of the plates of an iron ship. I have no disposition to exaggerate or even to enforce these objections, but they have hitherto prevailed to prevent any ship from being built on this plan, and it is certainly exposed to this difficulty, that to try it fairly, requires a very large ship to be built; the tongues of wood can only be as thick as the plates between which they are forced, and in small ships with thin plates they would give no sufficient foundation.

The plan which I propose may be regarded as a *mezzo-termine* between these extremes, with the advantage of being available for every size of ship, and having great elasticity in its application to produce whatever amount of galvanic action may be found on further experience desirable.

It has already been proposed as a method possible of application to our largest iron-clads, to fill up the hollow in the side of the ship between the inside and outside strakes with wood, and to fix the sheets of zinc over and in contact with the iron surface, fastening them into the wood; this would give a flush surface to the ship, a proportion of about one-half of contact with iron and with wood, which would probably give a very good result as to cleanliness. I have myself strongly recommended in certain quarters the trial of this plan—it is, in fact, out of this that my present proposition has arisen—but the objection has prevailed, and I have felt compelled to acquiesce in it, that a thin filling of wood $\frac{1}{2}$-inch to $\frac{3}{4}$-inch, which is about what our largest ships will allow, would be of doubtful sufficiency to hold on the zinc.

It is precisely with this insufficiency that I have proposed to deal, and I submit two alternative methods of doing so, which the model and drawing will at a glance explain;

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what is done is simply to increase this hollow to such an extent, as to give a thickness of wood strong enough to securely hold the fastenings of the zinc; one of these methods is adhering to the ordinary plan of building the ship with longitudinal lap joints, giving an inside and outside plate to interpose between these laps, before riveting them together, a band of iron the breadth of the laps of the necessary thickness, increasing thereby the relief of the outside plate; the other, which is in principle the same, is adopting a method sometimes used, to have all the plates home to the frames with flush edges, and to rivet these together by an outside longitudinal butt strap, increased beyond the ordinary proportionate thickness due to the strength necessary for the connection of the plates to that required for giving the relief wanted for a wood filling sufficiently strong as in the former plan.

In the drawing (Plate III.) I have taken $\frac{5}{8}$-inch as an average thickness of a ship's plating, and have inserted between the laps a $\frac{5}{8}$-inch strip, giving thereby a hollow of $1\frac{1}{4}$-inch, which filled in with wood, should, I think, be strong enough to hold the zinc; in the other plan the same result is produced by putting on a butt strap or outside plate $1\frac{1}{4}$-inch thick; this has been taken on the assumption that wood $1\frac{1}{4}$-inch thick is the proper strength to hold the nails for securing the zinc, but obviously the plan permits of this thickness being either diminished or increased as experience may prove desirable.

With respect to the bearing of these plans on the structural strength of the ship, I would observe that they are both simple, involving nothing in principle novel or difficult, or materially differing from the ordinary forms of iron shipbuilding; to the latter form, that of the outside butt-strap, no structural objection has occurred to me; there are, indeed, advantages in having all the plates home to the frames, and all the edges supporting each other: to the first form, that of the strip between the laps, it did at first occur to me that the riveting of three thicknesses, instead of two, was *per se* objectionable, and that the separation of the two lapped plates might, by increasing the leverage when strains come on the ship, increase the power of shearing or bending the rivets.

As to the first point, however, I have considered that, in ships built with plated keels, we are continually riveting together five thicknesses of iron, *i.e.*, the keelson, the two outside keel plates, and the two garboard strakes, and find no practical difficulty or objection to doing so; as to the second, I have made some experiments which have led to the conclusion that there is no real disadvantage, but rather the reverse. The introduction of the strip between the laps adds just 50 per cent., or what is due to the increased section of iron, to the power of the lap to resist all longitudinal strains; as to transverse strains, there is no difference, because the real point of weakness is at the rivet

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holes, where the sectional area is most reduced, and where, from the necessity of caulking, the space between the rivet holes is fixed at a maximum that cannot be exceeded; there is no question of shearing or breaking the rivets themselves, because, as riveting is now done, the power to resist this is always much greater than that of the plate itself weakened by the rivet holes: here is a point of minimum strength which cannot be helped; undoubtedly, if it were a question only of two plates riveted at the laps, the two plates would always break across the rivet holes, and those with the strip would break sooner than those without, simply because they would be more distorted,—the pull not being in a direct line; but then this is not the case in a ship, because the frames and stringers, and the whole combination of the ship tend to keep the plates in the direct line; as, against buckling, the plan will give greater power of resistance, the doubled lap will give that, the thickened liner will, so far as it goes, give the same result, and the wood filling will also give some addition of stiffness to the side.

Considering, in fact, that for all longitudinal strains the lap is made absolutely stronger than any equal portion of the solid plate, I express the opinion as worthy of consideration, that on this plan there is no necessity for double riveting; it adds nothing at all to longitudinal strength, and little, if anything, to transverse strength, and the plan proposed adds to the strength of the ship in the direction where it is really needed; and if it does at all reduce it, it does so where it is least needed. I am not aware of any instance in which a ship has been lost by a failure in a tranverse direction of the riveting, whether double or single. The largest ship afloat, the *Great Eastern*, is single riveted, and no sign of weakness has appeared from this cause.

So far as the structure of the ship is concerned, the strip between the laps is equally applicable to double or single riveting; but this has an important bearing on the question of cost. I have gone into this with reference to a ship like the *Volage*, and have found that, supposing no change to be made otherwise in the ship, she could be sheathed and zinced at a cost of less than £1 per ton over the ordinary plan, and an addition of half an inch to her draught; but if I am right in supposing that double riveting can be saved, then the comparative increase of cost would be reduced almost to nothing, and no increase would be made to the draught.

In the case of the outside strip being adopted, there would necessarily be a double row of rivets, and some addition to cost; but this addition would, I think, be very trifling, considering that the outside strips will contribute to longitudinal strength, and the liner is entirely saved, which is only a filling, and does little duty in giving strength, while the lateral strength is increased by having all the edges of the plates supporting each other. I think on this plan a ship can be built of equal strength, with no addition

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to the total weight of iron; the wood need only be fillings, the waste of a yard, put in diagonally with a few bolts through the side here and there to fix it. The zinc sheathing costs little—less than a third the price of copper, while all expensive compositions are saved. The first cost, therefore, will be little, and would soon be well repaid, doing even little better than zinc on wood at present; it would at least keep clean longer than paint, require less frequent docking, and reduce the time and cost of that operation. At present the cost of docking, cleaning, and painting an iron ship is 2*s.* a ton, or £200 for a ship 2,000 tons, and it requires four or five days in dock; while the zinc lasts—and I have an instance of its lasting seven years on a wooden ship, without being removed even to caulk the bottom—no painting is required, the bottom could be cleaned as the water leaves the ship in dock, and one tide would suffice for the operation at one-third of the expense.

To one feature in these plans I attach very great importance, *i.e.*, their elasticity and the power of varying their application as experience may shew to be desirable.

We can give any thickness we please to the wood for holding the nails simply by increasing or diminishing the strip; we can do this on a ship of any size, and what is perhaps the most important of all, we can regulate at pleasure the proportion of contact between zinc and iron; it is simply a question of the breadth of the plates, and in that part of the ship coated with wood, the galvanic action can be encouraged if necessary by driving the nails quite through and home to the iron, and I am informed that this has been discovered and acted upon of late in wooden ships sheathed with zinc. They are now increasing the number of iron nails fastening it, and providing that all iron bolts in the ship touch the zinc instead of being kept apart from it, and they have found that just in proportion as they do this they get a cleaner bottom. No facts, which in studying this question I have learnt, have been so satisfactory and so conclusive as those which bear upon this point; they go completely to establish the proposition that the zinc protects the iron, and that its cleanliness is simply and directly proportioned to the contact of the metals and the galvanic action.

In submitting this proposal to the First Lord of the Admiralty, and the Chief Constructor of the Navy, I have learnt from Mr. Reed that the plan adopted by him in building the *Inconstant*, to which I have referred as differing from the *Volage*, is substantially the same, although for a different object, as that of the outside strip. In her case the plates are flush longitudinally with a thick outside butt-strap, the hollows between being filled in with wood. This strap was introduced to afford a means of fastening the first thickness of wood, which is secured by screw bolts tapped into this strap, so that no holes are made through the side of the ship; to this the second wood sheathing is

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fastened, as in the *Volage*. It seems to me very likely that I am here to-day, simply because Mr. Reed was thinking of how to get the copper on to his ship, while I have been thinking of how to get the zinc there. I have been able to say (and this is the proposition now before the Admiralty) you can try the experiment I propose, without doing anything that you have not already done up to a certain point, and with the power, if the experiment does not succeed, of going beyond that point and doing all that you have already done in the *Inconstant:* you have only to build the *Inconstant* up to the point of the outside strip, and wood filling in between, with no other difference than that of putting the edges of your strip at such an angle to the side, as will hold on the wood, and stopping there to apply the zinc sheathing. If this succeeds, you save a great expense, if it fails, you can take off the zinc and go on and complete your ship with the wood and copper, like the *Inconstant*.

It would be difficult to imagine more favourable conditions for trying an experiment on which results of such immense importance hang; I need not here insist on the advantages which will be gained if this plan of zincing succeeds: if it does, it signifies that the iron ship can go on any distant station for long service, that the great cost of repairs of wooden ships, as compared with which iron ships cost almost nothing, will be saved; it signifies that, as it is certain the iron will be absolutely protected against injury from without, you have an imperishable ship; it signifies that a cleaner bottom means a higher speed maintained, or an economy of coal, and a power of steaming a greater distance with the same quantity; a reduction of docking and of its cost: supposing even that the zinc should not be quite equal to the copper, there are still the advantages of a flush surface which will add to speed, and of facility for hogging when at sea, and the preservation of the ship.

Perhaps I can give no better measure of the importance of this question than is founded on what has been done by our Admiralty in the five ships to which I have referred. The addition to the cost of these ships, caused by the wood sheathing and copper, is not less than £6 or £7 per ton as compared with what it would have been in iron ships; this means that the Admiralty have thought it wise to spend £110,000 or £120,000, for the sake of the advantage of such a clean bottom as copper gives, in spite of all the risks which it involves. Beyond question, the advantage is worth all and more than the cost while it lasts; and it is sought by methods on which all that skill and care can do to make them successful has been done: but I found on this an argument which, I trust, will prevail for making an experiment which involves no risk, can result in no loss, and affords at least a fair promise of success. After what has been, it would seem to be impossible to go back to a mere iron ship with paint or composition on her bottom: you must have a metallic sheathing; if that must be copper, then even if it be

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true (as said by a leading scientific journal, the other day) of the wood and copper plan, that if that be the best plan, then bad is the best; we must do the best, however bad. But, I say, build the ship so that you can try first the zinc; if that succeeds, you have made a great economy; if it fails, then you have lost little, and can go on and fix the copper. The question has, I think, gone beyond the stage of mere experiment on parts of a ship; it should be fairly tried on a ship at sea. Doubtless, there is much to be learnt, which can only be learnt in that way; much may be necessary to settle completely the problem. I have strong faith that this is the true direction, and shall be more than content if I have contributed even a step to its final solution.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. CHARLES LAMPORT: I apprehend that we are sitting here to-day as a jury to try the great question between Zinc and Copper. I have listened with very great attention to what fell from Mr. Grantham, and to his pleading on behalf of the material, copper. I listened to the statement of objections attaching to the system which he has put forward to day; but I failed to hear him mention the most vital objection which I conceive attaches to the application of wood under all circumstances, as an intermediary between iron and copper, namely, that it ignores altogether the principle which is involved, namely, chemical action. The objection which attaches to the application of wood as an intermediary, is simply this: So long as it is dry, it is efficacious, but as soon as it becomes saturated, it affords a medium of communication between the obnoxious copper on the outside, and the valuable iron inside, which it is so essential to protect. If, as Mr. Grantham proposes to do here, he puts on a covering of pine, the time which that sheathing will take to become saturated, I venture to say will not be very long, and the result will ultimately be most disastrous to the structure of the ship. So much as regards that matter. Now just allow me to call attention to this: At the Meeting in 1865, I stated, at length, the chemical law affecting the action of these metals. We have here, copper, iron, and zinc. The chemical law is perfectly simple; they have different modes, and different degrees of electro-positive action, and the action is in substance this—that that metal which is the most positive becomes the protector of all the rest, taking on itself the chemical destruction which would otherwise fall upon the other two. If you combine copper, zinc, and iron, the zinc absorbs the whole of the mischief—it is decomposed and saves the other two. If you combine zinc and iron, the same thing takes place. If you combine copper and iron, the iron suffers, and the copper is maintained in its integrity. With reference to the plan which Mr. Grantham has put before us as being the *ne plus ultra* of the copper combination, I will revert to the case of the composite ship which has been referred to; I say that the corrosion which has taken place there (pointing to the diagram), and which is leading to the condemnation of the most simple construction of composite ships, is owing to the neglect of this extremely simple law, and that the remedy can be enforced in the most inexpensive manner. I understand that Diagram No. 1 has the wooden planking attached to the iron plates, by means of galvanised iron bolts.

Mr. GRANTHAM: Iron, but not galvanised, because that system was condemned.

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Mr. LAMPORT: Very well. These are driven through the surface of the wood, and a plug is put in to prevent the copperised water coming in contact with the iron. We know that those plugs are very difficult things to put in so as to obtain perfect insulation. The water will penetrate by saturation, and when it comes in contact with the iron bolt, the bolt by chemical action becomes loosened in its aperture, and the whole structure is in danger. Mr. Grantham says, that the galvanised iron bolts were condemned. I also condemn them, for this reason—that if the galvanised bolts be thoroughly galvanised, and with a sufficient coating of zinc, and that zinc becomes decomposed, the bolts sooner become loose, and great mischief accrues. What is the remedy? Solely and simply this—that on the head of the bolt, before you put in the plug, you should put a disc of zinc of sufficient thickness to protect it for a sufficient length of time. I maintain, upon the simple principles and laws of electro-chemical action, that so long as that zinc exists, the iron will be perfectly insulated and protected. The proof of this I dare say is within the recollection and experience of every Gentleman present. I will however mention a fact with reference to a ship that I built—a wooden-frame ship, braced with iron. It was done in the infancy of that plan, and three years before Lloyd's adopted it as a necessary rule in the construction of timber ships. These braces, where they came in contact with the bilge water, which was tainted with copper or yellow metal particles, were subject to chemical action. In order to prevent that, I laid, without any trouble whatever, a strip of zinc sheathing between the ceiling of the ship and the iron. Nine years afterwards, when one of these ships was repaired, I had an opportunity of seeing what the result of my precautionary measures was. I called to it the attention of Lloyd's surveyor at Sunderland, where the ship was being repaired, and I am happy to say that the result was entirely satisfactory. The only injury that appeared to have resulted to the iron strapping was, that instead of its having the black appearance which it had when it came from the rolls it presented a beautiful silvery appearance. The iron itself was entirely protected, and there was no corrosion whatever. I venture therefore to say, that until Mr. Grantham will go further than he has done, and put something intermediately between the two that will perfectly insulate the iron from the saturation of the planks, so as to obviate the influence of the water and through it of the galvanic and chemical action, he will not effect the object which his most ingenious arrangement is intended to accomplish. On the other hand, I say to those who are building composite ships, and are inclined to look coldly on that simple and efficacious plan, that if they will only add a little zinc in combination with the head of the bolt, they will protect it, and the danger and mischief so much apprehended will be entirely obviated. I will mention further—as to galvanising;—that every person familiar with galvanising knows how frequently the metal is what is called *burnt*. I have myself tried galvanised iron bolts, driving them through a hole in hard wood, and I have found that the wood has had the effect of detaching the zinc coating which had previously been put upon the surface of the bolt, so that the whole of that which is thought to be a protection is stripped off, and the naked iron is put in the aperture, leaving only fragments of zinc to meet the chemical action which is so much to be dreaded from its disastrous consequences. I have thought it well to bring these few facts before the attention of the Meeting; and I will conclude my observations by saying that I give my vote most unhesitatingly on behalf of the defender of zinc as a sheathing for iron ships.

Mr. WILLIAM POOLE KING: Having had forty years' experience in the use of copper sheathing in African waters, which are very acid, I will first speak of the plan which Mr. Bell has laid down for

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protecting the bottoms of ships from fouling. Fouling, as I believe, may be generally known, arises from cirripedes, commonly called barnacles. The nature of this so-called shell-fish is, that in a prior state of its existence it is a swimming animal, and fixes itself upon any surface in the water—generally water not very far from the shore. I believe in mid-ocean there is no such thing, but near shore there are several species of the same genus of these animals. After the female animal fixes itself from swimming, it throws a mucus on the surface. This mucus has the property of soon casting down a film of carbonate of lime, and other testaceous matter. It covers much space, and increases in tropical climates to the extent of six inches in length. In more temperate climates it is not so long; but it all has this quality, that it emits matter from itself, and does not take matter in; so that however poisonous the substance may be upon which it fixes, it has no deleterious effect upon the animal, but it lives and increases, and as long as the surface remains firm, the animal will go on living and increasing. It is, therefore, quite impossible and futile to attempt to get rid of the animal by any kind of poisoning, and the only way in which we can divest ourselves of its ravages is by having a surface which continually drops off in scales and loses itself. Now I will first consider Mr. Bell's proposition of sheathing a ship with zinc. All chemists know that zinc is about one of the most oxidisable of metals—certainly the most oxidisable of all economical metals. But it has this quality, that the oxide is insoluble, it clings very hard, and it also increases in size when it is formed. So that the oxide forms upon the metal, it clings hard to the metal, and it expands so much that it fills up every kind of crack or crevice, and a film of oxide covers the metal, and protects the rest of it from the ravages of oxygen; so that we can use zinc as an economical metal so long as it is covered with this film of oxide of zinc. I will now speak of this film of zinc. If it exists in water where it is not dissolved and washed away, it then allows barnacles or cirripedes to collect upon it. The cirripedes throw their mucus upon it, the crust of zinc remains, and the barnacle expands. The oxide of zinc has the property of being exceedingly soluble in acids, and there is a free acid in tropical waters in general, especially near the shore, where it is mixed with vegetable matter. If there is the least quantity of acetic acid in the water it has the effect of washing away the zinc sheathing as you would see sugar dissolve in water. I have used, on the Coast of Africa, zinc sheathing of nearly $\frac{1}{8}$-inch in thickness, but coming in contact with the acid waters of that coast, it has melted away in the course of twelve months. It was entirely gone. It was washed off as if the ship had been covered with brown paper. In the northern seas, I am aware that zinc lasts for a considerable time; but I have generally seen ships, even in those oceans, covered with the pedunculated barnacle, and the sessile barnacle too, and the bottom of the vessel has to be cleared off very often. In my opinion, zinc is an inferior substance altogether, and is not applicable for Her Majesty's Navy. No doubt there is an economical use in the employment of zinc. It has the property of protecting every iron bolt it comes in contact with; therefore it is a very economical thing. You cannot sheathe an ordinary ship with copper, for the galvanic influence entirely eats out every iron bolt in her; therefore inferior ships find that it is an advantage sometimes to use zinc sheathing. But zinc sheathing is so inferior a substance, that I am sure Her Majesty's Navy will never adopt it with any advantage, and I very much doubt whether any large ships will ever employ it. Having spoken so far in disparagement of the use of zinc, I will not say a word about the manner in which it ought to be fastened on, for I think it ought not to be fastened on at all. I will now address myself to Mr. Grantham's system of fastening on copper sheathing. I think copper sheathing has been found by experience to be the very best material for protecting a ship from being impeded by barnacles; and I

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believe his system of fixing it upon wood is a tolerably good one. About two years ago, I built a composite ship in Sunderland, and have had some experience in its use on the coast of Africa. It was a composite ship, and the framework of it was made so strong that it did not require to be assisted by the strength of any wooden planking; therefore I was able to fasten it how I pleased. Sailing her on the coast of Africa, amidst these very large barnacles, it was necessary to protect her with copper. I first gave her a bottom 4 inches in thickness of pine plank. Then, in order to entirely separate the iron framing from the copper, I fastened the sheathing with screws of 3 inches in length, from the inside, outwards; so that there was at least one inch of timber free as an insulator between the copper sheathing and the iron frame. This I found to answer the purpose tolerably well—I will not say completely, for this reason: It is very difficult indeed to get a ship carpenter to enter into galvanic considerations; and however much you may impress upon him the necessity of insulation, he always will contrive to drive some copper bolt through, in order to take strength from the outside to support his own work—a thing which is entirely unnecessary, still it is very difficult to prevent; and wherever a bolt has been so driven, the insulation is broken, and immediately on the iron near the bolt a certain degree of corrosion appears. Few Gentlemen have an accurate notion of the large amount of galvanism that is set up by a large surface of copper immersed in salt water. The galvanic influence is very extensive. The action is not carried on merely at the top of the bolt, but is carried through from the copper to the iron. It communicates itself to the bilge water which it finds inside the ship, and gives it terrible energy to decay every bolt and every plate with which it comes in contact. I will say a word upon Mr. Grantham's plan of having a metallic stern-post. The metallic stern-post is really as good a conductor of the galvanic influence as Mr. Grantham could have chosen, and I need not tell you that it will distribute the galvanic influence of the copper bottom, by communicating it to the bilge water and to the frames inside; therefore it must have a very prejudicial effect on the frames of the ship and the plates which are inside. But there is this to be said in favour of it, namely, that it does not give its galvanic influence to a single point, but distributes it throughout the whole of the plates of the ship. It communicates it to the bilge water, its influence is distributed everywhere, and the decay is general and not partial. What makes a bolt so very destructive when it becomes chemically affected, is, that a small part of it giving the galvanic influence to the inside, gives it to a local part, and in that local part setting up decay and oxidisation. The metallic stern-post and stern would tend to distribute it everywhere, which is perhaps an advantage.

Rear-Admiral Sir J. C. DALRYMPLE HAY, Bart., M.P., F.R.S.: I am sure this subject must be a most interesting one to the Meeting and the Public generally. The two Papers which we have heard from Mr. Grantham and Mr. Bell, have gone very far I think to point out the direction in which further enquiry should be made. From what fell from Mr. Bell, every person must recognize of how much greater importance the subject must be to men-of-war, than it can possibly be to other classes of vessels. Men-of-war must always be ready to keep the sea as long as it is necessary for the public service they should so. A passenger ship, or a cargo ship, has always the opportunity, at the end of a certain time, of being docked and cleaned, and resuming her duty in a fit and proper state; but the whole value of a man-of-war is, that she does not require docking, for she does not always go to those parts of the world where docks are found. It is, therefore, essential that she should be able to perform her duty and keep the sea without the necessity of being docked. This is an important consideration when we bear

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in mind the vast expense that would be entailed in constructing docks to receive our vessels, supposing it were necessary to dock them for the purposes of cleaning. But if they are copper-sheathed, it will not become necessary to put them in dock merely to clean them. The mischief arising from the simple iron bottom, the contact of the metals, and from other causes, is so patent to everybody present (and I may say, also to the Admiralty) that the necessity that these new ships should be docked has become more and more apparent. I think, from the two Papers which have been read, we may gather that the interposition of wood is necessary; and I may say, that in my opinion, it is extremely valuable, because it acts the part of a fender to the ship in case she takes the ground. It also offers itself as an insulator, and as a mode of attachment. What fell from the Gentleman who spoke last (Mr. King) on the subject of the duration of zinc, I can confirm to the fullest extent. I had the honour of serving in one of Her Majesty's ships, the *Trinculo*, on the coast of Africa, which ship was coppered with zinc, if I may be permitted to use such an expression, and I can confirm him in saying that whereas other ships of the same character, sheathed with copper (the *Pelican* and *Pelorus*, which were on the coast of Africa on the same service), were sent home, and afterwards served two other commissions (in the case of the *Pelican* without requiring to go into dock to be re-coppered), the *Trinculo*, after something less than five years' service, was stripped of her zinc, and the wood at the bottom left quite exposed.

Mr. BELL: What was her condition as to cleanliness?

Sir J. C. D. HAY: On the wood, in various parts, the barnacles were attached; but where the zinc was there was no great amount of barnacles or of weed. Towards the very close of the service, our ship having had no opportunity previously of being docked, though in the clear waters of the coast there being plenty of opportunity of ascertaining what was going on, there was the cleaning process, which took away not only the barnacles but the zinc as well.

The PRESIDENT: Do I understand you to say that in five years the zinc had completely worn off the wood, so as to leave the wood exposed?

Sir J. C. D. HAY: Yes. There where patches were the zinc and felt was interposed, but there were also patches where the wood was absolutely bare. In fact the whole sheathing had been destroyed by the chemical action which she experienced on the coast of Africa. But the point I was going to direct attention to was this:—If it be true that the zinc will exfoliate with the same regularity as copper, I quite agree that as it is a cheaper substance, and has various valuable properties, especially the property of protecting iron, it certainly ought to be adopted. But if, on the other hand, the insulation suggested by Mr. Grantham can be made complete, and we can protect the ship with copper, whose good qualities we know, instead of the zinc, whose good qualities we are not yet acquainted with (and from the circumstances to which I have alluded, I confess I have some doubt of its success), I think in that case, the extra expense of the copper ought certainly to be incurred. It ought not to be on the ground of expense alone that zinc should be adopted. If, as has been pointed out by some speakers, the insulation cannot be made complete, and great danger must arise to the iron ship from contact with the copper, then we must fall back upon the zinc; but if, on the other hand, insulation can be made complete, I should be inclined, so far as I am at present informed, to give my vote in favour of copper.

Mr. C. F. T. YOUNG: It seems to me that any thinking practical man can form but one opinion upon such a subject as that which now occupies our attention. So long since as the year 1821, the danger of

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putting copper upon an iron vessel was fully admitted, yet we are here discussing the same thing to-day. Some years ago, Mr. Robert Dickinson took out a patent for sheathing ships, by putting wood over the iron, and then placing copper upon it. What the result of that patent was, I do not know; but we have the evidence of men of such high authority against the employment of copper on iron ships, that I am really surprised to find that it is being done at a very considerable expense. We have the late Professor Faraday, a gentleman of the highest authority and well acquainted with the subject—in which no man was better up, if I may be excused for using such an expression—who says that the association of iron also with other substances, if metallic, will much affect it, and that the mere attaching of a ship that is coppered to a cast iron pier or wharf by an iron cable, will cause galvanic action to take place. If you take a small gallipot, and place in it a piece of copper, and a piece of zinc, and make a connection by means of a telegraph wire, you will see the enormous distance to which it will go. Perfect insulation must be effected, otherwise all the mischief accrues. Speaking mechanically, there is no difficulty in producing perfect insulation between the copper and the iron hull, provided you leave the ship in the dock or on the slip where the water does not get; but the moment you put her in the water, the difficulty arises. I am not speaking of the strain which the ship is subjected to; but the mere pitching and tumbling, and the wash of the water over the copper on to the iron is quite enough to set up that galvanic action which is so mischievous. It is not the less sure or the less injurious in its action, because it is not seen, or because the copper is placed at a distance from the iron. We can easily imagine the extent of the injury that will accrue. Take the case of a ship with several thousand square feet of copper upon her. As long as that copper keeps clean, the insulation is complete; but the moment it gets foul, that moment the insulation is shown to be broken. I ask any shipowner present, how he would like to go to the expense of stripping it all off (and you must take the whole of it off, for I defy you to find out where the exact locality of the mischief is) and reclothing the ship? In eight months the iron plates of the *Royal Oak* were eaten in to the depth of $\frac{3}{8}$-inch, and the plates of the French iron-clads were eaten in to the depth of $\frac{5}{8}$-inch, in about five months; and it was said by a gentleman of the French Navy, that they would have to renew their iron-clads in five years, if some means were not adopted to prevent such wholesale destruction. Now then comes the important question. Here are two different materials. Wood is one sort of thing—iron is another, and they are put together on the hull of a ship. Any one who has been to sea will know how difficult it is to balance the strain on an iron ship, and determine how much strain is upon the iron, and how much is upon the wood. I defy any one to balance it with any exactness, under all circumstances. I have here a specimen of insulated copper on iron, which I may state was tried at Shoeburyness under the superintendence of the Iron Plate Committee. Every precaution was taken, still there was that sort of coupling existing by the water that corrosion began to take place. It is a mere question of amount. Of course, 10 square feet of copper on 10 square feet of iron will produce a larger amount of corrosive action than would be produced by one square inch of copper on one square inch of iron. Dr. Medlock (a very able Gentleman) says that he would advise you "Not even to think of using copper in any shape as a paint for iron ships." Dr. Noad says, that "Copper in any form ought not to enter into the composition of any substance having the object "of protecting the bottoms of ships." Dr. Normandy, who takes the same view, remarks that copper paint is not at all suited to the painting of iron ships. Captain Selwyn has well remarked that "It "would be cheaper to build our ships of copper than to go into plans for making copper bottoms to iron "ships." Captain Engledue, of the Peninsular and Oriental Company, says, "I have at various times

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"tried preparations of copper on iron ships, and in every case found the iron and rivets damaged." Mr. Scott Russell has remarked, respecting the employment of copper on the submerged portions of iron ships, that there will be chemical action of some kind, unless very serious precautions are taken. Mr. Siemens has said that copper sheathing appeared very inapplicable; and with regard to the insulation of the two metals by the interposition of a layer of wood, it was hardly to be supposed that the two enormous surfaces could be long kept perfectly separated without metallic connection being formed between them. Mr. Radermacher says, "I believe that iron and copper are two dangerous elements to have "together in sea water." We all of us know that that is so. He further says, "I believe that to produce "galvanic action does not need contact of the two metals; but I believe that even wood saturated with "salt water will form a great conductor, and produce galvanic action." Mr. Murray gives his testimony to the same effect, and says that the copper salts dissolve in sea water, they injure the iron by galvanic action, and do not keep clean more than four or six months. M. Becquerel, the eminent French chemist, has shown the great danger incurred by the use of copper in connection with the hulls of iron ships. I may add, that Mr. Grantham has himself given some very good illustrations of it. He speaks of a composite ship built with iron frames, wood-planked, and coppered, and says, "The result was just what "we should have supposed. The bolts were found to have perished, or were beginning to perish, in "consequence of their approximation to the copper." We have known that that is so, and have seen it constantly. The idea seems to be (which I cannot understand for a moment) that because copper keeps clean on a wooden ship, it is therefore the only thing that can be applied to an iron vessel. That does not follow at all. The proper combination appears to me to be zinc; and iron and zinc seem to be the only materials you can properly use together. And I may say that this is nothing new. It has been known, I can hardly say how many years. Mr. Bakewell in his "Rudiments of Chemistry" gives us a table of it all. Isaac Watts, C.B., Thomas Hawkesley, Gmelin, Professor Brande, Professor Faraday, Dr. Fairbairn, Professor Rankine, and a host of other eminent Gentlemen, all speak of zinc as being the only thing you can safely apply. Therefore, I think, the object being to preserve the ship, to keep her clean, to build her economically, and work her economically, common sense would dictate to us to take that material which is the most likely of all others to accomplish that object. I cannot get out of my head the notion that if one tithe of the trouble and cost of discussing and trying the merits of copper on iron were spent in building a ship, sheathing her with zinc, and testing her at once, it would be much better, and we should then be able to judge of the respective merits or advantages of the two materials. Mr. Bell has remarked that the mode of construction has been the cause of Daft's system not making any progress. I must respectfully but emphatically deny that, because it is not so. The reason why Daft's system has not yet been gone on with has been because we have not received the necessary Reports from the Admiralty. But when we come to the question of construction, and putting forward the three thicknesses proposed, as a novelty, all I can say is, that it is no novelty at all, because it was known long ago.

The PRESIDENT: I do not rise with any view of stopping this very interesting Discussion, but I regret to say I am obliged to appeal to you for indulgence, finding myself in rather an unexpected difficulty. Judging from past experience, I was led to expect that the proceedings of this morning would have closed early in the day, but this very interesting Discussion seems very likely to be prolonged, (I confess I should be sorry if it were not prolonged), and my position is such that I am compelled to leave. I have the less reluctance in asking you to grant me this indulgence, from the knowledge that

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in all probability Lord Lauderdale will succeed me. My place will, therefore, be filled more efficiently in my absence than if I were to remain; and I take my leave of you, adding my congratulations upon what I consider to have been upon the whole, a very successful Meeting (applause).

[The President then left the Chair, which was occupied by Lord Lauderdale for the remainder of the sitting.]

Mr. JOHN SCOTT RUSSELL, F.R.S.: I would venture to say a few words, if you will allow me, upon this very interesting subject. There are two questions, it seems to me, of a totally different nature before us. One question is structural, *viz.*, the best way of fastening on the material and the sheathing and protection of the outside without injury to the ship, taking into consideration all the contingencies to which the ship may be liable. I will be as short as possible in the observations which I have to make, and merely say that it appears to me that the method which Mr. Grantham has finally adopted of attaching an inner layer, by means of longitudinal strips, has so many mechanical advantages that I should be very reluctant to see any other plan adopted. Mr. Grantham is quite right in saying that it is of the utmost importance to leave his ship entire and unperforated, and every mechanic knows that if you trust for side action, or the resistance to side action, to the accuracy with which a bolt happens to fit a hole, you do that in shipbuilding, which, in engineering, we have long dismissed as wholly unworthy of that science. Mr. Grantham puts on the outside of his ship something which costs nothing, because it is, as he has justly said, a part and parcel of the necessary strength and material of the ship. I give, therefore, my vote absolutely and entirely in favour of that system; but I would beg merely to ask Mr. Grantham why he does not make the outer edge of his angle iron, T-iron, that is, angular both ways, and insinuate, which he can very easily do, a layer of timber between the longitudinals. I see the difficulty of doing it, and I see a very simple way of remedying the difficulty; therefore it is that I am led to ask why Mr. Grantham does not do that, because it would add greatly to the strength of his structure, and would render the application of any bolt not only unnecessary, but absurd and preposterous. He has some good reason, no doubt, for not doing that. When we go a step further, I see another great advantage, of a practical nature merely, in Mr. Grantham's arrangement. A Gentleman who spoke a short time ago, said that he had his layer of wood screwed on from the inside with screws which did not come within more than an inch of the surface, and then he most wisely added that he found he could not trust to the shipwrights carrying their holes exactly the 3 inches through, and not sometimes going to the extent of 4 inches. That is quite true; but you will observe that by Mr. Grantham's plan, the whole of that danger is taken away. A perfectly smooth skin is finished off before they lay on the second layer, and they lay on the second layer of planking on the smooth skin. Now I come to this objection, which I think is an objection that Mr. Grantham will be grateful to have stated. The objection is, that between his first and second layer of planking, he has no insulating substance. But it would be the easiest thing in the world to cover that layer, after it is on, with the most beautiful sheeting of canvas impregnated with marine glue, or any other of those insulating substances with which we are acquainted. It would be the easiest thing in the world to put a sheet of that impermeable substance over it, and it is an easy and practicable method of applying an insulating substance. Then, when we come to the second layer of timber over the first, it becomes not only extremely easy, but extremely safe, for he has only to take care that he does not put into the hands of any of the shipwrights bolts or fastenings which are long enough to go through, and they cannot send them through; and cannot

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make a blunder, for they can make a nail or bolt shorter, but they cannot make it longer. Here you have, therefore, as it seems to me, a well-considered plan. Then, when we go a step further, to the laying on of the copper, that is done in the ordinary way. Allow me, therefore, to say that, having had the greatest possible jealousy of the wholesome position of an iron ship, having been very much afraid of coppering an iron ship, having been very unwilling to tamper with an iron ship, and having been very jealous of that hard enemy, copper, coming within a moderate distance of an iron ship, I feel more disposed to entrust an iron ship to the care of Mr. Grantham's method, as I now see it, than anything else I have yet seen. But there is another question of quite a different nature—and I will not venture upon it, because I am not a chemist—I mean the question between zinc and copper. I know merely in a rough and practical way the disadvantages of these. I am very fond of copper for its remarkable quality of maintaining a nice, smooth, slippery skin, by which the resistance of a ship to going through the water is enormously diminished. Allow me to tell you that I have made experiments upon coppered ships, and have measured the resistance to going through the water by dynamometrical means on a large scale; and although I do not go quite so far as my friend, Mr. Grantham, I am able to say that a ship the size of the *Warrior* will have more than one-third less resistance to going through the water, will burn more than one-third less fuel, or will go with the same power a proportionate degree faster with a copper skin than with an iron one, supposing the copper skin to be in a state of tolerable cleanliness. What the virtue of copper is, I cannot quite tell. I do not know whether you have stroked copper when it has been covered with sea water; but I have, and can tell you that clean copper, stroked with your hand, when it is covered with sea water, has the same greasy feeling upon it that the skin of a fish has, and, somehow or other, it slips through the water with marvellous ease. Therefore, I have a great affection for copper. I am afraid that zinc has not that smoothness, but that is a question for the future. I am afraid that zinc is liable not only to corrode rapidly, but to corrode rapidly in patches, though probably we may find a cure for that. I will just say one word, in the shape of a suggestion. I have taken a sheet of copper and a sheet of iron, and I have connected them together by the mechanical structure of an iron ship. I have placed them under salt water for twelve months, and I have seen the enormously injurious effect of the copper upon the iron. But I have also taken a neutral metal, which is neither zinc nor copper, but a mixture of both. That neutral metal is called Muntz's metal, and is used for the sheathing of ships. It is not so handsome as copper; I do not like its colour so well, and, as a matter of taste, I should prefer copper; but I have buried in the sea a plate of Muntz's metal, and a plate of iron, with all the arrangements of an iron ship connecting them together, and at the end of twelve months the sheet of Muntz's metal was as clean as when it went in, and the surface of the iron was perfectly uncorroded. I therefore venture (not being a chemist) upon the question of chemistry, merely to say that the late Professor Faraday, when I asked him, told me that Muntz's metal was pretty nearly a neutral metal in relation to iron. It is not neutral in relation to sea water, because it is well known to corrode. It is well known to peel off, and it is well known to detach the animals which fix upon it in the same manner that copper does. I would say, therefore, that perhaps, under all the circumstances, Muntz's metal is not unworthy of a trial, as being less an enemy to iron than copper is, and as being capable of retaining a smooth surface, and gently scaling off, so as to keep the bottom clean.

Captain JASPER H. SELWYN, R.N.: I have but few observations to make, and I may begin by saying that I think I can establish some points which may prove useful to those who are pursuing the

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subject. First: this is not a question of chemistry, but rather one of galvanism. Secondly: it is utterly impossible to establish insulation at all, and if you did, you would destroy that very corrosion which you value so much on the outside of a ship. There must be communication, and it must exist between the positive metal outside and the negative metal inside. Mr. Scott Russell has very properly pointed out a metal which nearly fulfils the required conditions. All we have to do is, to seek for a metal that will absolutely fulfil them, by galvanic experiments, and not by experiments on ships' bottoms at first. Having done that, we may proceed to attach it without the slightest care about its touching the iron. If you apply all the wood you like under the water, with the pressure due to the surface column, you will find that at some point the insulation is affected, the water has passed, and that one point, though it be only as absolute a point as a mathematical one, will be sufficient to convey it to the whole. If you wish to guarantee that no water shall leak in at any part of it or at any period of its existence, it is an utter absurdity. Therefore, do not let us run after fallacies, but let us rather seek to determine the true scientific action of the metals upon each other; leaving that to decay as rapidly as it ought to decay, and no faster, which is within the compass of galvanic knowledge, and so keep a clean bottom to the vessel. Without that decay, all the composition in the world will not keep barnacles off, whereas, with it, no attachments will take place. This does not depend on acid waters or other waters. I can myself speak to a very wide experience of barnacles all over the world. I never saw the country where there were not barnacles in salt water;—up the rivers, out in the ocean, and everywhere you passed. We begin by poisoning shell-fish, we next go to insulation, and we miss all the time the one simple investigation which would insure us as to its results from the first step to the last.

Mr. LUNGLEY: As my name has been mentioned in connection with the zinc sheathing, I would ask permission to shew some models which I have.

The CHAIRMAN (Lord Lauderdale): This discussion has continued so long that I think we must now call upon Mr. Grantham and Mr. Bell to reply to the observations which have been made.

Mr. GRANTHAM: I did not intend mine to be a competing plan with that of Mr. Bell when I placed it before the Meeting; therefore I speak with some hesitation. However, they have been treated as rival plans before the Institution, which I should carefully have avoided as far as I was concerned; but seeing that both plans have been taken into consideration, I suppose it will be necessary that I should speak upon them, and perhaps the Meeting would wish that some views which I have should be expressed upon the differences which exist between the two methods. I have very little to say upon the plan which I have myself brought before this assembly, except in reply to the remarks which have been made by Mr. Scott Russell. Mr. Scott Russell asked me a question with regard to the shape of the iron which comprises the longitudinal frame. I may say, generally, that this is a matter of detail to which I have given great attention for the last eighteen years since I first introduced this plan; therefore he will perhaps excuse my going into all the arguments which might be necessary upon such a point, and allow me to content myself by merely saying that this form has been decided upon after much and careful consideration. I may add that Mr. Scott Russell's suggestion with regard to giving another protection, and with regard to placing an isolating substance between the inner and outer casing, has not escaped attention, and it is possible that we should shield the inner casing with some non-conducting substance. It has been suggested that that might be accomplished by a thin sheet of lead, which has been found to be exceedingly efficacious in iron ships.

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Mr. W. P. KING: Lead as a non-conductor, do you mean?

Mr. GRANTHAM: Yes. I may make one remark with regard to what was said by Mr. Lamport. I fear he has done that which I was accused by Mr. Reed yesterday of doing, and has not exactly understood my Paper, otherwise he would not have made the observation he did about the saturation of the wood by the water. A great part of my Paper went to shew that the mere saturation of the wood by the water would not have any injurious effect in the way of promoting galvanic action, and I read an extract from a Paper by Mr. Mallet, a well-known authority, explaining how that would be. As I shall have to refer to that Gentleman's name again, perhaps I should state that he was employed for about twenty-five or thirty years in investigating this subject by the British Association in connection with Dr. William Fairbairn, and he has given to us the result of his experience, as applicable to this peculiar subject, with a model like this before him; therefore the remarks which he has made have immediate reference to this question. He says that the mere saturation of wood will have no sensible effect whatever, and to have an injurious effect, it must be by a stream in and a stream out—that is, it must be by a change of water; but if it is merely a small quantity of water, and that water remains without any movement, that it will be perfectly innoxious. That, then, is the answer to these questions. Now I think I need not again refer to my plan; but I shall be obliged to refer to my friend Mr. Bell's plan, because the two have evidently now the spirit of competing plans. In order to bring them before you as simply as I can, I will make only a few remarks. I have long given attention to this question, I gave attention to it when it was propounded by my friend Mr. Daft, who is now represented by Mr. Young. Mr. Daft began with copper, which he has now repudiated, and he now flies to zinc. We all began with copper, and are now flying to zinc, and I fear not upon very good grounds. I know that Mr. Mallet makes use of these observations—"All the various devices of coating with other metals such as with zinc, usually called galvanising, have been found to be perfectly nugatory under the ordinary circumstances of exposure and constant moisture. Even in perfectly pure fresh water, galvanizing, or coating the surface with zinc, is a palliative of corrosion, and nothing more. In sea-water it is entirely useless, and as applied to iron ships it would be absolutely hurtful; because, independently of any ill effects on the toughness of the iron, one of the effects of removing the thin coating of zinc, is, that a thin coating of carbonate of lime would be deposited on that which remains, and on that thin bed of lime plants and animals would attach themselves." I do not pretend to say one word upon that point. I am not a chemist, and therefore merely read what Mr. Mallet has said without making any observations upon it.

Mr. LAMPORT: Will you allow me to ask where that was said?

Mr. GRANTHAM: It was said in a Paper which was read at the Royal United Service Institution in the year 1862. Now, not only is it important to consider the question of the action of the zinc, which I do not pretend to say one word about here (and I have only read the opinion of a celebrated man), but I fear I must differ from my friend, Mr. Bell, which I do with great reluctance, as I am sure he will believe, when I express an opinion hostile altogether to his mode of attaching zinc, or any other metal whatever, to iron ships. I understand that Mr. Bell proposes that there shall be what I may call recesses made in the ship, in the way as he has explained, by which thin planks may be inserted at intervals, and that a sheathing of zinc shall be spread over and nailed to that planking. But the intermediate part will

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be left unsupported, and it will merely pass over the plate, which, I suppose, will be from two to three feet wide. It will be entirely unsupported, and merely attached to the next plank when it meets it. I am entirely opposed to all those who suppose that metallic sheathing of any kind can be attached to an iron ship directly, in this manner. In the first place, I believe that this planking would immediately become loose; or if it remained tight, it would be such an insufficient support to the remainder of the zinc, that the zinc itself would soon become loose. In the next place, I feel convinced that the slightest collision between any pier or ship, of so enormously heavy a body as a ship of war, would have the effect of immediately displacing that metallic sheathing. These were my first plans, and I abandoned them as being utterly impracticable for use as regards iron ships. Therefore, upon these grounds, with great reluctance, I feel myself bound to say that I differ from all those who advocate this mode of attachment, or any similar mode. I have long since, even in this Institution, expressed my decided opinion against the plan proposed by Mr. Daft, upon the same grounds. There are other disadvantages in Mr. Daft's plan, but the main ground is the insufficient mode of attaching the metallic surface to such a heavy body as a ship must necessarily be. When such a force comes into action, I do not think that any metallic surface, attached in that manner, can remain sound. I have only one thing further to remark. I felt that in my Paper it was necessary, upon a public question, that I should make some allusion to the plans used by the Government. I did not then allude to what my friend, Mr. Bell, has now called upon me to speak about, *viz.*, the change of plans by Mr. Reed. Mr. Reed knew that my plans were the first of the kind, and that I was the first to introduce them to him, but he did not follow them out in all their details. He adopts one plan, but immediately deserts it, and then adopts some other plan. That is a ground upon which we may say, and I think fairly, that Mr. Reed has no settled plan, and the plan which he has now adopted may perhaps to-morrow be again changed. I do not wish to be understood as making any complaint about these matters, though I think there is fair ground for it; but I wish merely to shew that there has been a change of plans already in the Government system.

The CHAIRMAN: I am afraid if we did not change our plans, in the present days of shipbuilding, we should be very far behind.

Mr. GRANTHAM: I quite agree, my Lord. Mr. Young referred us to some authorities, to shew that if a coppered ship were attached to an iron pier by an iron chain, the chain would form a means of communication, and would carry the corrosive action to the pier. No doubt that might be so; but we shew that the whole is so insulated that galvanic action cannot take place.

Mr. LUNGLEY: I wish to state that I have a few models, showing my method of construction, which I think it my duty to bring forward. This is no rival plan, nor anything in the nature of a rival plan; but it is the exact plan which Mr. Bell has been reading his paper upon. I could not sit here and allow such things to be said as have been said, and go away without saying what I knew about it. This is my plan, and this is the model of it (exhibiting a model). I should not have said anything about it, had not Mr. Bell thought proper to use my name in connection with the matter. After what has taken place, I think I am only right in making this explanation, in order that there may be no misconception. My model shews the same plan as that to which Mr. Bell has referred.

The CHAIRMAN: This is not at present before the Meeting, therefore we cannot have any discussion upon it.

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Mr. LUNGLEY: Quite so, my Lord; but as I am here, after what has been said, I wish to protest against the plan belonging to Mr. Bell,—that is all.

Mr. BELL: I shall not detain you long by what I am about to say in reply. I may first say that the model which Mr. Lungley has produced I have never seen or heard of before. If he has proposed a plan similar to mine, all I can say is, that I shall be very glad to give him any credit that may attach to that plan, though my proposition is made quite in ignorance and independently of his. As to the remarks which have been made, I have nothing to complain of, and (it appears to me) very little to answer. What Sir John Hay said was really to me most welcome, for the effect of what he said was rather to advocate zinc as the proper material to put on iron ships. The fact mentioned by him, that it totally disappeared in five years, proves one of my points,—that is to say, that you can make it go with sufficient rapidity. That it may go too rapidly probably is an objection to the plan; but when Sir John Hay told us that it lasted five years, I think he adduced a very strong argument in the favour of its use. This must always be remembered: that if the zinc disappears, that disappears and wears away which we want to wear away, and the iron—the foundation, which we wish to preserve,—remains; and in the proportion of the wasting of the one, is the preservation of the other. I will refer for a moment to a remark which Mr. Grantham was good enough to make. He said, "If the ship comes in contact with a rock, or anything else, and the sheathing is taken off, the water at once gets to it." Really that is the very objection I have to putting copper on an iron ship; for when that happens in the case of a coppered vessel, the galvanic action, arising from the copper on the ship, completely destroys the iron. Let that happen with a ship sheathed with zinc, and there is no such mischief accruing. If the water gets to it, it will accelerate the destruction of the zinc, and that is all. This, to my mind, affords the strongest objection to putting the copper on an iron ship. One of the very points to which Mr. Grantham referred in his Paper puts this objection most strongly. He told us there was not a ship which went to the Baltic during the Russian War that did not get a hole knocked in her bottom. Let that happen to an iron ship sheathed with wood to which the copper is attached, and you destroy the insulation upon which you depend for the security of your ship, and you make a commencement of its destruction. I do not know that it would be possible to adduce a stronger ground for objecting to putting copper on an iron ship than these facts afford. With respect to the rapid destruction of the zinc, one point ought to be considered. Zinc, as an article of commerce, is very unequal in quality; and if zinc be impure, that is, if it be alloyed with any other metal, every other metal with which the zinc may happen to be alloyed is an enemy to that zinc; and if you have zinc mixed with impurities and a number of other metals, each one of them will create an action which will tend to destroy the zinc. What we want, in order to have a fair trial of zinc on the bottom of a ship, is to have the zinc perfectly pure, and then I am quite certain that its advantages would become apparent. I shall make but one observation upon Mr. Grantham's plan, and I am sure he will believe that I make it in the same friendly spirit that I know he entertained with regard to myself, when he alluded to my plan. I had some experience in the building of the *Volage* and *Active*, and am well acquainted with the plans of the *Inconstant*, and I would point out that, between Mr. Reed's plans and those of Mr. Grantham, there is really no very substantial difference. They all go upon this—that you must have the complete iron skin, because that is the only thing that will give you the rigidity necessary for the preservation of the form of the iron ship, so as to afford you a chance of obtaining the required insulation. We know that when

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a wooden ship is broken, she is lost; but when an iron ship is broken that does not follow. The one point of difference between the plans I must look upon with some degree of suspicion, and that is with reference to the external angle iron—not on the score of strength, because that is right enough; but that which I have my doubts about (and which was avoided in the plans of the *Volage* and *Inconstant*) is with regard to the insulation. There is also this other point which occurs to me. You depend for the prevention of the water getting from the copper to the iron skin, upon the perfect tightness of these wood fillets between the two angle irons. In the case of the *Volage*, you have nothing but a wood covering; that will expand and contract, it will be acted upon uniformly, and you can make it tight much more easily than you can make absolutely tight a joint between wood and iron. I do not say that that is any great disparagement of the plan, but it strikes me as an objection. I am not so strong an advocate of zinc as utterly to ignore the advantages of copper, though I think that zinc will be found to supersede it. In conclusion, I may say that I go with Mr. Grantham to this extent—that something must be done to protect the bottom of iron ships. Whether it be copper or zinc that will best effect that object, has not been determined. You have made some experiments with copper, and very likely it may be necessary to make more. You have not made experiments with zinc, and it is the making of those experiments which I recommend; and I think there are the strongest possible *prima facie* grounds for hoping that some better mode of dealing with the question may become apparent than we have at present at our command.

The CHAIRMAN: I think the Meeting will allow me to thank both Mr. Grantham and Mr. Bell for their very interesting and valuable Papers. I am afraid we must come to the conclusion that we cannot arrive at any decisive opinion as to which is the best plan of the two. Some Gentlemen have urged that it is quite impossible to insulate the copper from the iron. If that be the case, the copper will not answer. One thing that appears to me to be in favour of the zinc is, that it is not necessary to insulate it from the iron, but that on the contrary it is better that it should be in contact in some measure. So far, that is in favour of the zinc. With regard to what my friend, Sir John Hay, said, that the zinc sheathing of a vessel which was on service only lasted five years, I can only say that I have known many instances in which the copper has not lasted more than five years. I have known instances at Portsmouth, where, although the ships have not moved out of harbour, the copper has been found full of holes in five years. It must be borne in mind that copper does not last for ever; and if the mischief is done merely through the wood being damped, there would be very great difficulty in cutting off the communication.

[On the conclusion of the Discussion on these Papers, the following remarks were made.]

Mr. LAMPORT: I wish to give notice, that at our Meeting next year, I will read a Paper, "On a "Simple Plan of applying Zinc in a Fluid State."

Mr. MERRIFIELD: My Lord, the next Paper which we have, is one by Mr. Charles Haswell, "On "the Location of Independent Steam Fire and Bilge Pumps in Steamers." It falls to me to read that; but there are several notices of motion on the paper, and it is a question for your Lordship to consider

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whether it would not be better to take it as read, as it will be in the *Engineering* newspaper shortly, so that we can at once proceed with the other business.

The CHAIRMAN: Yes, I think that will be the better course.

Mr. MERRIFIELD: Then we will take Mr. Haswell's Paper as read. I should state that I have received some other Papers, which have come in since; they were not given me at the commencement of the Meeting, but they were asked for at the same time. There is one by Mr. Holland, "On the "Measurement of Horse-power," another by Mr. Reynolds, "On an Instrument for Measuring the "Deviations of the Compass," and a third by Admiral Paris, "On Sea-going Turret Ships." I think, my Lord, as those Gentlemen have been kind enough to prepare the Papers for us, we should take them as read.

The CHAIRMAN: Yes, let them be taken as read.

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ON THE LOCATION OF INDEPENDENT STEAM FIRE AND BILGE PUMPS IN STEAMERS.*

By Charles H. Haswell, Esq., Civil and Marine Engineer, New York, U.S., Associate.

[Read at the Tenth Session of the Institution of Naval Architects, 19th March, 1869; the Right Hon. the Earl of Lauderdale, K.C.B., Vice-President, in the Chair.]

Of all the instruments and appendages connected with a marine steam-engine, and the provident fitting of a steamer, the independent steam-pump—or donkey, as it is termed—stands pre-eminent in importance; both on account of its general utility, and its being under many very probable and oft-occurring circumstances, indispensable to the safety of a vessel.

The applications of this instrument extend from the ordinary operations of a bilge-pump and a boiler-feed pump, to those of a fire and a hold-discharge pump.

When, therefore, the extended, and in many cases, the indispensable operations of this instrument are duly considered, it would seem to be imperative that it should be located where it can be most readily reached, and where it can be operated for the longest period without being submerged by water, enveloped in smoke, or cut off by fire.

It occurs, however, as a rule of British and European practice, that it is located in the hold of steamers, immediately upon the lower engine-room floor; this practice, taken in connection with the insufficient capacity of the pump for the general purposes of fire and leaks, would seem to have arisen from the functions of the pump, as viewed by the constructors of the engines, being restricted solely to the operation of feeding and pumping-out boilers.

The cases in which the location of the pump in the manner referred to is objectionable, are as follows:—

1*st.*—A leak occurring in the furnace or water-bottom of a boiler, and the hot vapour arising therefrom precluding access to the pump, and the setting of it in operation,

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whereby the water escaping from the boiler, not being replaced by the operation of this pump, would soon expose the tubes or crown-plates of the furnace to be burned, and the boiler would thereby be rendered unsafe for operation.

2nd.—A leak in the hull of a steamer suddenly occurring from a collision with ice, another vessel, a pier or sunken rock, or the disruption of the propeller-shaft stuffing-box in a screw steamship, whereby the influx of water would be fully equal to the combined capacities of the pump and engines to discharge. The distance between the pump and the floor of the vessel, or the level of the water in the hold, would be so little, that any arrest of the pump from continuous operation, for adjustment or repair, would involve its submersion before it could be set in renewed operation.

3rd.—A fire occurring upon the main deck of a steamer, whereby the smoke would be drawn into the engine and fire rooms by the draught of the furnaces of the boilers, and this pump rendered inutile by the impracticability of reaching it to set it in operation.

4th.—A vessel grounded, or stranded, upon a sand or soft bottom, and leaking; her pump, from the ingress of sand and mud into her hold, would require frequent clearance; the delays consequent upon which would cause the pump to be submerged before it could be freed and set in operation.

The only defence that has ever been advanced for this violation of regard to the safety of a vessel, in locating this pump where, in many cases as here shown, it would necessarily be inoperative, is, that in the event of the hold being flooded with water, the fires in the furnaces of a boiler would consequently be drowned, and that the steam wherewith to operate this pump being obtained from the boilers, its functions would cease with the drowning of the fires.

Admitting this position to be strictly tenable, it does not meet the conditions of this pump being arrested in its operations by sand, mud, smoke, or the escape of steam. The position advanced, however, is not one of general application, as in a majority of cases, and especially in this country, there is an independent boiler connected with this pump, which, when located upon the main or spar-deck, and acting independently of the engine boiler, would not have its functions affected by the influx of water into the hold of a vessel.

The common plea, that a pump located in the hold of a steamer, below the water-line, will operate more effectively than if located upon the main deck, is only advanced by some engine-drivers, whose conceptions of a steamer are restricted to the operations of the engines and their dependencies, or by some owners of steamers, who are disinclined to incur the cost of a removal of the pump to a proper location.

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In this connection the capacity of this pump, proportionate to the dimensions of the vessel, is worthy of consideration; and, as a further rule of practice, the capacity of this pump in British and European steamers is much inferior to that in use in this country.

The general security of lives in British vessels, under the stringent requirements of Lloyd's Rules, has not generally opened the subject of the propriety of using a steam-pump for other purposes than these referred to, as confined to the operation of the boilers of a vessel; for, in many cases, this pump cannot be used to draw water from the bilge or hold of a vessel, and has not any fire-hose connections beyond the immediate precincts of the engine-room.

The capacity of this pump, proportionate to the vessel in this country, may be judged of from the following cases.

A British steamer, now in this port, built upon the Clyde as late as 1867, and belonging to a leading Company in the extent and character of its trade, presents the following cases:— $\frac{(l-\frac{3}{5}b)\times b\times\frac{1}{2}b}{94} = 3{,}230$ tons has but one independent pump, having a water cylinder of 1 gallon capacity, or a discharging capacity of 12,000 gallons per hour, or 3·7 gallons per ton per hour.

The new steamers of the Pacific Mail Steam Ship Company, built in this city in 1867, present the following cases:— $\frac{(l-\frac{3}{5}b)\times b\times\frac{1}{2}b}{94} = 4{,}200$ tons have four independent pumps, having water cylinders of $17\frac{1}{2}$ gallons capacity, or a discharging capacity of 136,500 gallons per hour or 32·5 gallons per ton per hour.

In further support of the position assumed, I submit that there have occurred very many cases where steamers have foundered, been burned, or wrecked in consequence of the location of their independent steam pumps in their holds. Three cases, and important ones so far as the loss of lives and property are concerned, can but be familiar to all.

The *Arctic*, foundered at sea in 1854, had two independent pumps of a combined discharging capacity of 31,000 gallons per hour, and an attached boiler, all of which were located in her hold. When her bottom was perforated by collision with the sharp prow of an iron steamer, the influx of water was superior to the capacity to discharge it, and for the following causes:—

1*st.*—Her independent boiler could not be put in operation until steam was raised in it.

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2nd.—Her floor being filled in solid, her bilge injections could not operate effectually until the water was fully two feet in depth, in consequence of the roll of the vessel.

3rd.—At the time, sufficient water had flowed into the hold for the bilge injections to operate with their full capacity, the additional depression of the vessel occasioned by this influx of water had reduced the number of revolutions of the engines and consequently their capacity to discharge the inflowing water, added to which, the water at that height washed the water-bottoms and ash-pits of the boilers, and reduced their capacity to furnish steam to operate the engines.

Thus, with a constant flow of water, the capacity to discharge it was being rapidly lost.

It occurred, however, that there elapsed a period of four hours after the collision, before this vessel sunk, and as a computation made by me of her entire weight as a mass, less the actual displacement of every particle of her and her cargo, gave but a difference of 1,000 tons, it appears that the discharge of this weight of water, or 65,570 gallons per hour, would have left this vessel free of water, and enabled her, so far as that collision was concerned, to have reached a port of safety.

Now, as the capacity of her bilge injections, at even the reduced number of revolutions of ten, would have been equal to 80,000 gallons of water per hour, it is manifest that the loss of this vessel at this time is directly attributable to the location of her independent pumps and their attached boiler.

The *Austria* was burned at sea in 1858, in consequence of the smoke from a fire upon the main deck pervading the engine-room and suffocating the watch, and as a consequence precluding the operation of her pump as a fire-engine.

The *Britannia* lately foundered at sea by the flow of water into her engine-room and the submerging of the independent pump.

The remedy I propose for this objectionable manner of the fitting of a steamer is to require this pump to be located upon the main, or tonnage deck, and to have an independent boiler attached to it, located upon the main deck, or preferably upon the spar-deck, in vessels having two or more decks; and that all passenger steamers be required to have this boiler ready for operation during the night, or during the prevalence of a fog.

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ON HORSE-POWER.*

By J. S. Holland, Esq., C.E., R.N., Associate.

[Read at the Tenth Session of the Institution of Naval Architects, 20th March, 1869; the Right Hon. the Earl of Lauderdale, K.C.B., Vice-President, in the Chair.]

The principal use of the steam-engine at its first introduction was to pump water out of mines; it easily followed that the new engine should be compared with horses, then in use for pumping, hence the term horse-power of an engine. Watt would undertake to make an engine do the work of so many horses. Being generous, he considered that a horse could raise 33,000 pounds one foot high in a minute; he fixed upon that for his horse-power. And although he knew that the mean pressure per square inch of his piston would be more than 7 pounds, he, to avoid all cavil with his customers, generously fixed upon 7 pounds as one of his factors in calculating horse-power.

Knowing that a long stroke engine could work easier at a high velocity than a short stroke one, he formed for himself a table of velocities of pistons for various strokes; and, at the time, it was formed on sound principles. So far as marine engines are concerned that table has long been obsolete. The 7 pounds are still retained, but the engineer is allowed to fix his own velocity of piston in his tender on negotiation with the shipowner. This brings me to the subject of this Paper. It is the false statement in the tender that I object to. Let us see what takes place at the beginning of a pair of marine engines. Assume that, after every consideration has been given to the subject, a power of 6,000 horses will have to be developed. He calculates what he can do in the way of pressure on the piston; he then fixes his velocity, which being determined, the diameter of cylinder follows as a matter of course; he then determines the fire-grate and heating surface of his boiler, and the work is done. All this time he has never thought of such a thing as nominal horse-power. Yet there is something else to be done. If the shipowner likes to have his engines working up to six times their nominal horse-power, clearly there is nothing left for the engineer but to christen his engines 1,000 nominal horse-power, and if the shipowner likes to be cheated a little more, you have only to

* Received 20th March, 1869.

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christen the engines 600 nominal horse-power, and you have ten times the nominal horse-power. You may accommodate the shipowner to any extent, but you must not tamper with the power to be indicated.

A case is now before me. An engineer stated in his tender, that the revolutions would be forty-four per minute; in working they went more than eighty-eight per minute, the pressure was about 22 pounds: now the pressure being over three times the nominal and the velocity twice, he counted over six times the nominal horse-power, and was patted on the back accordingly. If we are to have nominal horse-power retained, we must stick to the old 7 pounds, and reckon fairly and honestly the velocity expected. Then, if the engineer has made no blunder, the engines will move very nearly at the expected velocity, and if they do, and give out three times the nominal power, we know that there was a pressure of about 21 pounds. In the case I have named, the engineer knew well that his engines would go eighty-eight revolutions; he made his screw and his boilers to suit that number of revolutions. The question may be asked, why did he give forty-four revolutions? The answer is plain enough: there is a demand in the market for engines, that, under one pretence or another, can be said to have contained their nominal horse-power so many times in their indicated power, and where there is a demand there will always be a supply.

It is against this practice I enter my protest.

If shipowners and shipbuilders knew the contents of this Paper, we should have little more chuckling of six, seven, or ten times the nominal power. If nominal horse-power is to be retained, let the pressure be still 7 pounds; let the engineer state fairly his expected velocity, and let credit be given to him for getting as much pressure into his cylinder as he can from a given boiler pressure, and for coming near to his predicted velocity.

As for nominal high pressure, there is no such thing. As it would be better to keep nominal power and indicated power as wide apart as possible, I would propose that what is very nearly an average, 10 pounds, should be taken as the mean pressure.

Nominal horse-power has been called a commercial measure; if it ever was, it is no such thing now. Engineers know nothing about it; they are required to produce so much effective power and they set about to do it. It will weigh so much, cost so much, and they make up their accounts.

I propose to abolish the term nominal horse-power altogether; it is not only useless but pernicious. Shipbuilders are not called on to make vessels carry six or ten times their nominal tonnage, and I ask why should not engineers be allowed to be put on an equality with them, and have the privilege of calling a spade a spade?

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ON AN INSTRUMENT FOR DETERMINING THE DEVIATION OF SHIPS' COMPASSES.*

By W. F. Reynolds, Esq.

[Read at the Tenth Session of the Institution of Naval Architects, 20th March, 1869; the Right Hon. the Earl of Lauderdale, K.C.B., Vice-President, in the Chair.]

The rapid extension of iron shipbuilding which the present generation has witnessed has been accompanied by the development of a practical difficulty in the art of navigation, namely, the deviation of the compass caused by the disturbing influence due to the magnetism of the ship's iron. This difficulty has been sought to be overcome in many ways, such as the introduction of permanent magnets and soft iron, the unequal painting of the compass card, &c. The magnetism of the ship's iron, however, depends a great deal upon the induction of the earth and frequently alters considerably, from changes of latitude, and from other causes; it is therefore almost impossible to make permanent corrections of the errors of the compass by artificial means.

This being so, a ready appeal to a principle independent of all magnetic influences becomes desirable.

The true bearing of an object, either terrestrial or celestial, being known, the actual position of the ship can be ascertained by the use of a compass or dumb card with a pair of sights in the case of terrestrial objects, or by an azimuth compass in the case of celestial bodies.

The reference to the heavenly bodies, however, involves a consultation of tables or the time azimuth chart, &c.; this is a process which is found in practice to be but sparingly adopted by the officers of ordinary merchant ships, especially steamers, who, amid the pressure of other and manifold duties, are apt to depend too much upon the deviations as tabulated by the adjuster. It has consequently been thought that an instrument working somewhat on the principle of the sun dial, will be found to be preferable, the sun's meridian distance being invariably known with sufficient accuracy to furnish the requisite data for an observation.

* Received 20th March, 1869.

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It is to such an instrument that I venture to invite attention, and in placing it before the Institution, I wish it to be distinctly understood that I do not claim the credit of the first application of the idea, other instruments depending upon the same principle having already been made.

These instruments, theoretically perfect in their construction, are, as I understand, practically defective when used under certain conditions.

When a ship has much wind on her beam there is an extent of heeling over which may seriously affect the compass, owing to the ship's deck not being parallel to the card (the plane in which it was adjusted). As a clinometer must therefore be consulted before reliance can be placed upon any observation for determining the deviation, I have applied one to the instrument I am about to submit for your consideration.

The wind which causes the heeling over also affects the steadiness of the action of instruments exposed to its influence. The Palinurus, as I have named my instrument, is not affected by such a disturbing force, as the whole apparatus is flush with the top of the box in which it is contained; the heeling over of the ship causes the weather side of the box to be raised, and that, of course, completely shelters the working parts from the action of the wind.

The mechanism of the instrument is very simple. It consists of a hollow half sphere, around the outer edge of which a plate containing the points and degrees of the compass (the vernier for which is on that edge of the box which is placed towards the ship's head): this plate is so fixed as to be capable of being moved (by means of the milled head) partially round the bowl. A segment of the inner edge of this plate is divided to degrees, the vernier for which is on the top edge of the bowl, so that, by turning the milled head, the plate may be set magnetic, and the bowl and hour circle—as it may be called—true. This corrects for the variation.

The hour circle is deprived of its upper half, as it would hinder the shadow from falling on the lower half, especially when the sun has but little declination. It is slung by its ends, which are at right angles to the vernier on the bowl, in such a manner as to sweep the inside of the latter.

Fastened to the centre of the hour circle is a sector, the upper edge of which forms a line with the vernier on the top edge of the bowl when the instrument is set for 0° latitude.

At each end of the sector is a socket to carry a pair of sights, which are required when the sun is not bright enough to cast a shadow, or when observing the moon or a star, the tail of the sight being always placed at the meridian distance on the hour circle.

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By placing either end of the sector upright, and setting the tail of the sight at O, the instrument may be used for taking ordinary bearings.

The whole apparatus revolves upon a centre, and is hung in gymbals with a balance weight beneath.

As already mentioned, there is a clinometer on the side of the box facing aft.

The following are the instructions for using the instrument:—

1.—Set for variation by turning the screw at the south point.

2.—Set the latitude pointer to ship's latitude at time of observation.

3.—Find the apparent time at ship (say within five minutes), and turn the instrument by means of the knobs at east and west, until the shadow of the edge of the sector cuts the time on the hour circle.

The point now at "Ship's Head" is the course the ship is on (magnetic), the difference between which and the binnacle compass is the deviation of that compass on that point.

A pair of sights are supplied which can be fitted to either end of the sector, for the purpose of taking bearings of the moon and stars, or the sun, when not bright enough to cast a shadow.

When using them (having set the latitude pointer), set the tail piece to the time on the hour circle, and turn the instrument as directed in Rule 3, until the object is observed through the slits.

In high latitudes, and also when using the sights, it will be necessary to lift the hour circle, &c., out of the bowl by means of the ends projecting at east and west.

By placing the sector upright, the sights may also be used for taking magnetic bearings.

In conclusion, I beg to be allowed to remark that the object sought for in the construction of this instrument, is the production of a simple tool, capable of being readily understood and easily used by an ordinary mariner, without reference to any abstruse calculations, and which is as reliable and perfect in the practical results of its operation as are the methods and formulæ of the mathematical navigator.

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ON SEA-GOING TURRET SHIPS.*

By Vice-Admiral E. Paris, C.B., French Imperial Navy, Membre de l'Institut (Académie des Sciences), Associate.

[Read at the Tenth Session of the Institution of Naval Architects, 20th March, 1869; the Right Hon. the Earl of Lauderdale, K.C.B., Admiral, Vice-President, in the Chair.]

So many novelties are constantly appearing in naval construction, and their importance is so great, that it is absolutely necessary to become acquainted with them if we wish to avoid being some day very much out in our reckoning. This great variety also shews us that, far from its being necessary to limit our ideas, it is an advantage that everybody should be ready with his contribution. Moreover, as in these important questions it would be very pretentious for any one to make a tacit assumption that he alone was in possession of the means of arriving at a desired result, one should, I think, adopt that inter-communication of ideas and facts which so rapidly tends in the present age to bring everything to perfection through the criticism that it evokes. What would have been the fate of many of our modern marvels if they had been elaborated only in solitude? It would certainly have required more centuries than it has taken years to develop them.

It is this reason alone which has induced me to present myself before you as an author, and to shew you what a little experience at sea, the Universal Exhibition of 1867, and the ocean voyages of the monitors, have suggested to me in the way of producing a ship rolling as little as these, and as completely armoured as they are—but, at the same time, as habitable as ordinary vessels—and, while carrying her guns higher out of the water than the American turret ships, possessing that all-round fire which is their distinguishing characteristic.

As to rolling, we perceive at sea that one of the things least affected by the motion of the waves is a boat-hook kept upright by the weight of its iron end, a body in which the stability of form is *nil*, and the slender rod of which does not alter its displacement sufficiently to be set in motion during the short interval occupied by the passage of a

* Received 18th March, 1869.

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wave. A plank weighted at its extremity behaves in a similar manner, and does not roll. A solid of revolution, however, acts very differently; take, for instance, the case of a sphere or a cylinder, a finger can move it about in the water—it has no stability of its own—but put ballast into it, and it always returns to the same position, not having enough force in itself to move out of the vertical line passing through the ballast. The contrast between the slight motion of cask buoys and the large amount exhibited by towing barges is clearly seen when there is any sea on. Lastly, another example of moderate rolling is shown in the case of bodies which, though solid, have nearly the same specific gravity as water, such as a boat filled with water, or a piece of floating ice, *which move with the waves, but not more than they do.* The adoption of the first plan would entail an impracticable draught of water, and, moreover, perfect immobility is not desirable; the second is about to be tested in the Winans' yacht, and is likely to present many difficulties; while the third plan is exemplified in the monitor, and demonstrates the influence of form upon rolling, or rather the influence of that portion of the ship which is usually above the water-line, but which is dispensed with in the monitor.

The three cases I have quoted and compared with ordinary constructions, shew, that when the two causes of stability—weight and form—act moderately together, and especially when the effect of the latter increases with the inclination, or what is the same thing, causes the metacentre to rise, the motion of rolling becomes exaggerated, and, I believe, the form of maximum rolling is a semi-cylinder surmounted by a parallelopiped, which, speaking roughly, is the shape of a ship; especially if side weights bring to bear in addition the influence of their inertia. On the other hand, when one of the causes, weight or form, is almost exclusively in operation, the motions in a rough sea are very moderate; and we may see every day a raft rolling much less than a boat, whilst a boat-hook thrown overboard is completely immovable, which has caused it to be chosen as a wave-tracer, like the top for a roll-tracer; and experience has shown the exactness of these two instruments, whose construction is based upon known natural laws. They measure the movements of ships and waves in all their periods as Watts' indicator measures pressures.

It is, moreover, necessary to rely upon the well-established fact of the small motion of monitors, as the excessive rolling of iron-clad vessels, which is so prejudicial in action, and of which the sailors have been the victims, fully proves our ignorance of the laws that govern the rolling of ships; or if we know them, or if any theory upon this point exist, it would be unpardonable not to have applied it, and it is better to admit ignorance than negligence.

The monitor would seem then to be the best form for a ship of war, and in reality

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no arrangement surpasses it on the smooth waters of rivers where the crew have frequent opportunities of going ashore. But although these vessels have left their rivers in order to cross the Atlantic, and to circumnavigate their continent, it has only been during fine weather, and when escorted by two ships of ordinary build. The first *Monitor* was lost in a sea in which the boats of another ship could live. The *Weehawken*, as well as the *Affondatore*, was swamped from having opened the hatches to admit fresh air after a battle.

A navy composed entirely of monitors would be likely to suffer the fate of the Armada. The voyages of the *Miantonomah* and of the *Monadnock* in fine weather, and accompanied by two other vessels, no more prove that these ships are suited for true navigating purposes than the fact of the *Red White and Blue*, or of the raft of india-rubber cloth, crossing the Atlantic in summer, proves that *they* are. But as monitors do not roll, whilst all the new broadside iron-clads are worse rollers than the old vessels used to be, and even in moderate seas bury their guns under the waves, in consequence of their low freeboard, as well as expose the unprotected portions of their hulls, we must endeavour without depriving the monitor of its good qualities, to render it fit for habitation, and safe for navigation in all seas and all weathers.

In order to accomplish this, we must observe what are the conditions of stability of the monitor. Wide and of low free-board, it has its metacentre at a height which much exceeds that of any other form of ship; but if the monitor be inclined sufficiently for the sea to cover its deck, the metacentre is suddenly lowered, and the stability becomes so small that the vessel would capsize if the pressure on the sails should carry her beyond a certain point; for the stability is similar to that of an obelisk, which would fall if it were inclined 5 degrees. In any ordinary ship, everything takes place in just the opposite manner; its stability, moderate when the vessel is in the upright position and the metacentre low, increases when it is inclined; and Mr. Reed has shown that it increases in the ratio of the angles of inclination. If instead of an inclination there is a sloping of the waves, the power tending to move the ship increases in the same ratio as the angles between the plane of flotation and the plane of the waves, and sets in play all the weights of the ship to add their oscillatory movements to the rise and fall of the sea. In the monitor, on the other hand, the force which keeps it to the surface is enormous, since, when upright, or what is the same thing, when the water-level is the same on each side, it possesses as much as eight times the stability of the old vessels; whilst when the undulation of the waves causes the water to cover its deck, this stability disappears even more quickly than it increased in the previous case, to such a degree, that if there were a constant force in action, like the pressure on the sails, it would become dangerous if not stopped; but in the plans that we are considering, this security is obtained by the

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presence of the inner ship, which, when the outer one is immersed, becomes a support, and allows us, by varying the breadth, to regulate the stability as we choose.

These general principles being laid down, I have, I think, the means of realising them, by putting, as shown on the plans (Plate VI.), a very narrow but high ship upon a very low but broad and shallow one. The figures given for the stability in Table I. shew the results calculated for Plan No. 1 with upright sides (Plate VI., Figs. 1 to 4). The last column contains results founded on the assumption that the sail-power is equal to that of a three-decker.

In a word, without pretending to be clippers, these ships will not be wanting in sail-power. I have carried out the relation which exists between the moment of sail and the moment of stability of Plan No. 1 for the extreme case of the sail-power of a three-decker, and for different inclinations; and I have compared it with that of different ships given in M. de Fréminville's *Guide du Marin*, to which I am indebted for Table II.

But the stability can be easily modified at great inclinations by filling in the angle formed by the deck of the wide ship and the side of the narrow one (*see* Plate VI., Figs. 7, 8, 11, 12); and this would also receive the shock of the water, which will be certain to spread over the low deck. It may be observed, however, that instead of flowing freely from side to side, as in the monitors, the water is stopped by the intermediate ship; but it is probable that, retained sometimes on one side, sometimes on the other, it will rather tend to stop the rolling by its weight; since, finding nothing to displace, it does not lift the vessel as it rises. Apart from this difference, what I propose is thus entirely founded upon retaining the characteristic property of the monitor up to a limit sufficient to secure that the ordinates shall not spread enough to support the ship against an excessive surge, until they have previously undergone a sufficient diminution to prevent their causing uneasiness, which they would produce if they increased steadily with the list. The other arrangements of the drawings are only intended to take advantage of these conditions, and to utilize them for the armour plating and for the battery, as seen by the figures in Table III.

Thus the three types represented receive the armour shown in Table IV., and have their rudders covered by the overhanging stern as in a monitor. The armour of broadside vessels protects the orlop deck, but would be useless when they have 5 or 6 degrees of inclination, because the cylindrical shot would pierce the deck and would enter the ship, taking the protecting armour in reverse. It is thus preferable to have a horizontal surface of armour as strong and as complete as on the monitors, since it covers the lower deck even in the interior of the narrow ship, and by comparing the areas and their relative thicknesses it will be seen that it does not weigh more than the

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vertical sides of actual vessels, outside of their batteries. Placed above the deck planking it becomes a protection as real as it would be illusory if it were beneath.

The inner vessel has lattice framing extending to the bottom of the hold (Plate VI., Figs. 5 and 9), and is covered with thin plating which not only forms a rigid girder, running right fore and aft, but also a water-tight bulkhead, which bends in towards the extremities, leaving between itself and the outside plating a space that no ram could traverse without danger of breaking off. Amidships, where the distance between the two ships is considerable, coal spaces are introduced into the wing-passages, and except the armour which is necessarily placed outside, all the weights are concentrated as much as possible. Two other transverse bulkheads, of a similar description (Plate VI., Figs. 7 and 11), carry each turret, and I do not think that the very considerable weight of the latter could be better sustained and distributed than by these lattice-framed bulkheads.

The cabins, on one or two decks according to the size of the ships, would be as well ventilated as possible, and the upper decks, being of the usual height, would stand less chance of being covered with water than in a ship with straight sides. Nevertheless, as, with a head wind, the water would tend to cover the deck, it would be turned off by two small wash boards 50 to 60 centimètres high, (20 to 24 inches), which would turn it over the side. The bridge, following Captain Coles, would be very high, and would not interfere with the fire (Plate VI., Figs. 1, 5 and 9).

The position of the turrets would be copied from Captain Coles's plan, and their height, being greater than those in the monitors, would introduce as extra weight only that of the lower and fixed portion, instead of a central battery. The artillery would thus be well placed by being out of the reach of waves, and the line of fire would be interrupted only by the six legs of the tripod masts, instead of the ordinary six large sets of shrouds which are likely to foul the screw if shot away.

The *Captain* has its ports 3 mètres (9 feet 10 inches) above the level of the water; the *Rolf Krake*, 1 mètre 60 centimètres (5 feet 3 inches); the *Monarch*, 4½ mètres (14 feet 10 inches); the *Dunderberg*, 2 mètres (6 feet 7 inches); the *Dictator*, 1 mètre 40 centimètres (4 feet 7 inches); the *Nauset*, 2 mètres (6 feet 7 inches); the *Admiral Halsted*, 4 mètres (13 feet 2 inches); and the plans, 2½ mètres (8 feet 2 inches), and 5 mètres (16 feet 4 inches) for the portsills of No. 1; 4 mètres 70 centimètres (15 feet 5 inches) for those of No. 2; and 4 mètres 30 centimètres (14 feet 2 inches) for No. 3; The bulwarks, raised when at sea, would be lowered inboards, when the ships are cleared for action, and placed in the cavity formed by a wide waterway, instead of hanging outwards, exposed to the risk of being broken or bent.

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As for the anchors, I had designed for my part what Admiral Labrousse had long since proposed in a model, *viz.*:—to place them on deck by means of a jointed cat-head, raised by a winding tackle coming from the mast-head, of which the diagrams give a sufficiently accurate notion (Plate VI., Figs. 1, 8).

With the ordinary rudder a large number of men are required at the helm: it is therefore necessary to adopt the balanced rudder. I have proposed one with the axis bent on one side with lateral pintles, and capable of being shipped or unshipped under ordinary circumstances, without risk of having it disabled by a slight shock. It could be moved by hydraulic pressure acting in a curved cylinder like an elbow-pipe (Plate VI., Fig. 13).

I propose to use twin screws, which alone are suited to small draughts of water, which are the best propellers for manœuvring yet invented, and which afford a means of safety to the engines by dividing their power. Besides, the two screws are admirably suited to Woolf's engines, by causing the steam to pass from the small cylinder of one screw to the large cylinder of the other propeller, without the least mechanism, the valves alone regulating the motion, and the additional weight being confined to the enlargement of the two cylinders. I proposed this arrangement in 1863, in *L'Art Naval à l'Exposition de* 1862, p. 349. I have since made drawings of it, and I understand that it is now in use.

Lastly, I propose to build these vessels of iron, because that material alone resists the strains caused by the sea and by high speed, because iron stern-posts are not carried away when the ship is under steam, because, if the speed falls off, it is recovered again on docking the vessel, and because iron is the only material suitable for high speeds; at least until it is proved to us by experiment that the composite system can be adopted.

As I was not competent to make a working drawing, and to get out the weights of the hull, &c., I had recourse to M. Verlaque, the designer of the *Numancia*, the *Maria-Pia*, and of many iron-clad ships and mail boats. That Gentleman sent me from La Seyne a section and an estimate of weights, proving that the displacement is sufficient, and telling me that as he had constructed, and seen at sea, the *Scorpion*, built for Holland, he would willingly undertake the responsibility of building the proposed vessels.

In conclusion, I may be permitted to say that the turret ship always offers an oblique surface to an enemy's fire; and, consequently, that the thickness of the plating is increased in the ratio of the sines of the angles of incidence of the shot. Turrets, covered with plates of 25 to 30 centimètres thick (10 to 12 inches), are much stronger than

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broadside batteries of equal thickness, which must have open ports in order to bring their guns to bear, and must receive the projectiles in the direction normal to the surface. The contrast between the number of men killed on board the *Tamandaré* with those lost in the monitors in the River la Plata, has given a proof of this. With a few large guns, nothing beats the turret. I must observe, moreover, that the designs are susceptible of several modifications without their leading features being changed; that the relative dimensions of the two ships can be altered; that the angles where they meet can be rounded off, as well as that between the armour-belt and the deck; that the ships themselves can be lengthened and made finer, in order to obtain greater speed, or to carry more coal; and that when so treated they require less additional weight than would be necessary with any other system. Lastly, of the three plans, No. 2 is preferable; it has the same armour as No. 1, the same speed, is more manageable, and is considerably cheaper. No. 3 cannot be protected with armour of greater thickness than 15 centimetres (6 inches), without employing exaggerated dimensions for a single turret. All have the advantage of shallow draught, which enables them to approach land, to enter ports, or to pass channels which are closed to vessels of greater draught. This is a great advantage, especially as it involves no loss of speed. That this is so, has been proved in the case of the *Rochambeau*, and we may copy her water-lines without adopting her battery, which is cut up in every direction by large ports with very low sills.

[TABLE I.

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TABLE I.

Inclination.	Extreme Draught of Water.		Displacement of Hull, P.		Distance of Centre of Buoyancy. From L. W. L.		From the Middle Line Plane.		Height of Metacentre above Centre of Buoyancy, ρ.		Distance of Centre of Gravity below L. W. L.		Height of Centre of Gravity above Centre of Buoyancy, a.		Value of $\rho - a$.		Moment of Stability, M.	Moment of Sail, M1.	Value of $\frac{M}{M1}$.
	Mètres.	Ft. in.	Tonnes.	Tons.	Mètres.	Ft. in.	Mètres.	Ft. in.	Mètres.	Ft. in.	Mètres	Ft. in.	Mètres.	Ft. in.	Mètres.	Ft. in.			
Upright	6·750	22 1⅞	8,368	8,236	2·875	9 5	0·00	0 0	5·85	19 2½	0·58	1 10⅝	2·300	7 6½	3·550	11 7⅞	29,716	72,766	0·408
5°	6·765	22 2½	,,	,,	2·900	9 6	0·42	1 4½	4·05	13 3½	0·60	1 11½	2.310	7 7	1·740	5 8½	14,560	,,	0·209
10°	6·795	22 3½	,,	,,	2·950	9 8	0·73	2 4⅝	3·40	11 2	0·62	2 0½	2.335	7 8	1·065	3 6	8,912	,,	0·122
15°	6·840	22 5½	,,	,,	3·030	9 11½	1·02	3 4	3·30	10 10	0·65	2 1½	2·375	7 9½	0·925	3 0½	7,740	,,	0·106
20°	6·920	22 8½	,,	,,	3·120	10 3	1·29	4 2⅝	3·48	11 5	0·70	2 3½	...	...	1·065	...	8,912	,,	0·122

The centre of effort of sails is supposed to be 26·20 mètres (85 feet 11½ inches) above L. W. L.

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TABLE II.

NAMES OF VESSELS.	Value of $\frac{M}{M^1}$.	Ratio borne by Design No. 1 to each of the given Vessels for the Inclination of				
		0 Degrees.	5 Degrees.	10 Degrees.	15 Degrees.	20 Degrees.
Breslau, 100 guns, completely equipped ...	0·082	5·00 times	2·55 times	1·46 times	1·34 times	1·46 times
„ „ stores having been used ...	0·059	6·90 „	3·54 „	2·07 „	1·80 „	2·07 „
Tage, 90 guns, completely equipped	0·096	4·25 „	2·37 „	1·27 „	1·11 „	1·27 „
„ „ stores having been used ...	0·078	5·10 „	2·69 „	1·56 „	1·36 „	1·56 „
Breslau, completely equipped	0·076	5·37 „	2·75 „	1·60 „	1·39 „	1·60 „
Alceste, 52 guns, completely equipped	0·067	6·09 „	3·12 „	1·82 „	1·58 „	1·82 „
„ „ stores having been used ...	0·053	7·59 „	3·94 „	2·30 „	2·00 „	2·30 „
Jeanne d'Arc, 44 guns, completely equipped ...	0·063	6·47 „	3·31 „	1·93 „	1·68 „	1·93 „
„ „ stores having been used	0·051	8·00 „	4·10 „	2·39 „	2·07 „	2·39 „
Eurydice, 30 guns, completely equipped ...	0·077	5·30 „	2·71 „	1·58 „	1·37 „	1·58 „
Obligado, 10 guns, „ „	0·065	6·27 „	3·21 „	1·87 „	1·63 „	1·87 „
„ „ stores having been used ...	0·059	6·91 „	3·37 „	2·06 „	1·80 „	2·06 „

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TABLE III.—DIMENSIONS AND CALCULATED RESULTS OF THREE DIFFERENT DESIGNS OF SEA-GOING TURRET SHIPS.

	Design No. 1.		Design No. 2.		Design No. 3.	
Length of hull at L. W. L.	93·60 *m.*	307 ft. 1 in.	88·30 *m.*	289 ft. 8 in.	68·50 *m.*	224 ft. 9 in.
Breadth, extreme	22·00 *m.*	72 ft. 2 in.	18·00 *m.*	59 ft. 1 in.	15·50 *m.*	50 ft. 10 in.
Ratio of these two dimensions	1 to 4·25		1 to 4·64		1 to 4·3	
Breadth of inner ship	13·80 *m.*	45 ft. 3 in.	9·60 *m.*	30 ft. 6 in.	9·00 *m.*	29 ft. 6 in.
Ratio of breadth of inner ship to that of outer	1 to 1·594		1 to 1·968		1 to 1·72	
Outer diameter of turrets	8·50 *m.*	27 ft. 11 in.	8·00 *m.*	26 ft. 3 in.	8·00 *m.*	26 ft. 3 in.
Calculated mean draught	6·75 *m.*	22 ft. 4 in.	5·75 *m.*	19 ft. 0 in.	5·00 *m.*	16 ft. 5 in.
Ditto, with an extra supply of coal	7·20 *m.*	23 ft. 8 in.	6·10 *m.*	20 ft. 2 in.		
Volume of circumscribed parallelopiped for the calculated mean draught	13,900 $m.^3$	54,545 cu. ft.	9,646 $m.^3$	37,852 cu. ft.	5,309 $m.^3$	20,833 cu. ft.
Area of circumscribed rectangle at L. W. L.	2,059 $m.^2$	22,164 sq. ft.	1,677·7 $m.^2$	18,059 sq. ft.	1,062 $m.^2$	11,432 sq. ft.
" " " at ⌶	1,485 $m.^2$	15,985 sq. ft.	1,092 $m.^2$	11,755 sq. ft.	775 $m.^2$	8,342 sq. ft.
Displacement at calculated mean draught: Fore body	4,061 $m.^3$	15,936 cu. ft.				
Displacement at calculated mean draught: After body	4,103 $m.^3$	16,100 cu. ft.				
Displacement at calculated mean draught: Total	8,164 $m.^3$	32,036 cu. ft.	5,980 $m.^3$	23,466 cu. ft.	3,124 $m.^3$	12,259 cu. ft.
Displacement at calculated mean draught: Difference	42 $m.^3$	164 cu. ft.				
Displacement expressed in units of weight	8,368 tonnes.	8235·8 tons.	6,129 tonnes.	6032·2 tons.	3,202 tonnes.	3151·4 tons.
Area of immersed portion of ⌶	126 $m.^2$	1,356 sq. ft.	92 $m.^2$	990 sq. ft.	66·4 $m.^2$	715 sq. ft.
Area of L. W. L.	1,552 $m.^2$	16,706 sq. ft.	1,264 $m.^2$	13,606 sq. ft.	800·78 $m.^2$	8,620 sq. ft.
Displacement for each additional centimètre (0·394 inch) of draught	15·88 tonnes.	15·6 tons.	12·96 tonnes.	12·8 tons.	8·20 tonnes.	8·1 tons.
Ratios in Abstract Numbers: Of the volume of the hull to the circumscribed parallelopiped	0·588		0·588		0·588	
Ratios in Abstract Numbers: Of the area of L. W. L. to the circumscribed rectangle	0·754		0·754		0.754	
Ratios in Abstract Numbers: Of the area of ⌶ to the circumscribed rectangle	0.857		0·857		0·857	
Distance of centre of buoyancy from L. W. L. at the calculated draught of water	2·875 *m.*	9 ft. 6 in.	2·47 *m.*	8 ft. 1 in.	2·10 *m.*	6 ft. 10 in.
Height above the lowest part of the ship at the same	3·875 *m.*	12 ft. 9 in.	3·28 *m.*	10 ft. 9 in.	2·90 *m.*	9 ft. 6 in.
Height of metacentre above centre of buoyancy	5·85 *m.*	19 ft. 2 in.	4·87 *m.*	16 ft. 0 in.	4·15 *m.*	13 ft. 7 in.
Height of metacentre above L. W. L. at the calculated draught of water	3·00 *m.*	9 ft. 10 in.	2·80 *m.*	9 ft. 2 in.	2·05 *m.*	6 ft. 9 in.
Distance of centre of buoyancy from the after perpendicular	46·27 *m.*	151 ft. 10 in.				
Height of upper deck at the calculated draught of water	5·30 *m.*	17 ft. 5 in.	3·70 *m.*	12 ft. 2 in.	3·10 *m.*	10 ft. 2 in.
Height of bulwark of the armoured portion	6·90 *m.*	22 ft. 8 in.	5·30 *m.*	17 ft. 5 in.	4·60 *m.*	15 ft. 1 in.
" portsills of battery	3·00 *m.*	9 ft. 10 in.				
" " turrets	6·10 *m.*	20 ft. 0 in.	4·60 *m.*	15 ft. 1 in.	4·30 *m.*	14 ft. 1 in.
" bridge	7·70 *m.*	25 ft. 3 in.	5·50 *m.*	18 ft. 1 in.	5·80 *m.*	19 ft. 2 in.
" netting	9·30 *m.*	30 ft. 6 in.	6·50 *m.*	21 ft. 4 in.	6·10 *m.*	20 ft. 0 in.
" top of turrets	7·90 *m.*	25 ft. 11 in.	6·50 *m.*	21 ft. 4 in.	5·90 *m.*	19 ft. 4 in.

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TABLE IV.—EXTENT OF ARMOURED SURFACES AND THEIR WEIGHT.

ARMOUR ON VERTICAL SURFACES.	Design No. 1.		Design No. 2.		Design No. 3.	
Thickness of plating in armour belt	0·20 *m.*	8 in.	0·20 *m.*	8 in.	0·15 *m.*	6 in.
Length of armour belt (on both sides of the ship)	198·00 *m.*	649 ft. 7 in.	183·06 *m.*	599 ft. 7 in.	144·00 *m.*	472 ft. 5 in.
Height above the water at the calculated draught	1·00 *m.*	3 ft. 3 in.	0·80 *m.*	2 ft. 8 in.	0·60 *m.*	2 ft. 0 in.
Depth below „ „ „ „	1·70 *m.*	5 ft. 7 in.	1·75 *m.*	5 ft. 9 in.	1·50 *m.*	4 ft. 11 in.
Total width	2·70 *m.*	8 ft. 10 in.	2·55 *m.*	8 ft. 5 in.	2·10 *m.*	6 ft. 11 in.
Area above the water	198 *m.*²	2,131 sq. ft.	147 *m.*²	1,582 sq. ft.	86·8 *m.*²	927 sq. ft.
„ below „	336 *m.*²	3,617 sq. ft.	321 *m.*²	3,455 sq. ft.	216 *m.*²	2,325 sq. ft.
Total area of the ship's vertical armoured surface	534 *m.*²	5,748 sq. ft.	468 *m.*²	5,037 sq. ft.	302·8 *m.*²	3,252 sq. ft.
Ratio of the area above the water to that below it	1 to 1·7		1 to 2·08		1 to 2·5	
Weight of this vertical surface	833 tonnes	820 tons	728 tonnes	716 tons	356 tonnes	350 tons
Number of turrets	2		2		1	
Length of battery or fixed turrets	87·00 *m.*	285 ft. 5 in.	39·00 *m.*	128 ft. 0 in.	18·50 *m.*	60 ft. 9 in.
Height „ „ „	3·00 *m.*	9 ft. 10 in.	2·30 *m.*	7 ft. 7 in.	2·20 *m.*	7 ft. 3 in.
Area „ „ „	339·00 *m.*²	3,649 sq. ft.	91·00 *m.*²	980 sq. ft.	40·7 *m.*²	438 sq. ft.
Thickness of armour on ditto	0·20 *m.*	8 in.	0·25 *m.*	10 in.	0·25 *m.*	10 in.
Weight of battery or fixed turrets	527 tonnes	518·7 tons	176 tonnes	173·2 tons	78 tonnes	76·8 tons.
Total area of revolving turrets	159 *m.*²	1,712 sq. ft.	151 *m.*²	1,625 sq. ft.	75·5 *m.*²	813 sq. ft.
Weight of lower portion of ditto, 1 mètre (3 feet 3 inches) high; armour, 3 décimètres (12 inches) thick	124 tonnes	122 tons	116 tonnes	114·2 tons	58 tonnes	57·1 tons
Weight of upper portion, armour 25 centimètres (10 inches) thick	197 „	193·9 „	194 „	190·9 „	97 „	95·5 „
Total weight of revolving turrets	321 „	315·9 „	310 „	305·1 „	1·55 „	152·6 „
Area of vertical armour protecting rudder ...	15·0 *m.*²	162 sq. ft.	5·6 *m.*²	60 sq. ft.	3·9 *m.*²	42 sq. ft.
Weight of ditto	24·0 tonnes	23·6 tons	8·7 tonnes	8·5 tons	3·0 tonnes	2·9 tons
Total area of vertical armoured surfaces ...	1,037 *m.*²	11,163 sq. ft.	716 *m.*²	7,707 sq. ft.	439 *m.*²	4,726 sq. ft.
Weight, if these had armour of 2 décimètres (8 inches), uniform thickness...	1,687 tonnes	1,660·4 tons	1,116 tonnes	1,098·4 tons		
Real weight with the thicknesses adopted ...	1,724 „	1,696·8 „	1,223 „	1,203·7 „	592 tonnes	582·6 tons

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TABLE V.—EXTENT OF ARMOURED SURFACES AND THEIR WEIGHT—*continued.*

ARMOUR ON HORIZONTAL SURFACES.	Design No. 1.		Design No. 2.		Design No. 3.	
Thickness of plating on the exposed decks ...	0·05 *m.*	2 in.	0·05 *m.*	2 in.	0·04 *m.*	1·6 in.
Area of ditto	476 *m.*²	5,124 sq. ft.	512 *m.*²	5,511 sq. ft.	267 *m.*²	2,874 sq. ft.
Area taken as equal one-fourth of the same vertical surface	119 *m.*²	1,281 sq. ft.	128 *m.*²	1,378 „	72 *m.*²	775 sq. ft.
Weight of these exposed surfaces	185 tonnes	182·1 tons	199 tonnes	195·8 tons	83 tonnes	81·7 tons
Thickness of plating on the unexposed decks and the hatchways	0·04 *m.*	1·6 in.	0·04 *m.*	1·6 in.	0·03 *m.*	1·2 in.
Area of unexposed portions, battery or turrets deducted	617 *m.*²	6,642 sq. ft.	745 *m.*²	8,019 sq. ft.	431 *m.*²	4,639 sq. ft.
Ditto, reduced to one-fifth of the same vertical surface	123 *m.*²	1,324 sq. ft.	149 *m.*²	1,604 „	86 *m.*²	926 „
Weight of these unexposed portions	192 tonnes	189 tons	232 tonnes	228·4 tons	101 tonnes	99·4 tons
Total area of the horizontal surfaces without reference to their thicknesses	1,093 *m.*²	11,765 sq. ft.	1,257 *m.*²	13,531 sq. ft.	698 *m.*²	7,514 sq. ft.
Weight of these surfaces with their respective thicknesses	377 tonnes	371·1 tons	431 tonnes	424·2 tons	184 tonnes	181·1 tons
Total area obtained by reducing the horizontal surfaces to fractions of the vertical	1,279 *m.*²	13,768 sq. ft.	993 *m.*²	10,689 sq. ft.	597 *m.*²	6,426 sq. ft.
Total weight of armour of every description ...	2,101 tonnes	2,067·9 tons	1,654 tonnes	1,627·9 tons	776 tonnes	763·7 tons
RATIOS.						
Nominal horse-power of the engines	1,200		900		400	
Nominal horse-power for each square mètre (10·8 square feet) of midship section	9·52		9·67		5·42	
Number of guns in a broadside	7		4		2	
Vertical area protected for every gun	148 *m.*²	1,593 sq. ft.	179 *m.*²	1,927 sq. ft.	240 *m.*²	2,582 sq. ft.
Total area protected for each gun (the horizontal areas being reduced into vertical)	182 *m.*²	1,959 sq. ft.	246 *m.*²	2,647 sq. ft.	299 *m.*²	3,219 sq. ft.
Weight of vertical armour for each gun ...	246 tonnes	242·5 tons	308 tonnes	303·2 tons	292 tonnes	287·3 tons
Total weight of protection for ditto	300 „	295·3 „	410 „	403·5 „	388 „	381·8 „
Displacement for ditto	1,166 „	1,147·6 „	1,446 „	1,423·1 „	1,601 „	1,575·1 „
Number of nominal horse-power for ditto ...	171		222		200	
Guns firing right a-head from under armour ...	2		2		2	
Ditto firing right a-stern	2		2		2	
Volume of the outer ship above the water, taking the vertical sides up to the deck	8,225 *m.*³	290,343 cu. ft.	4,171 *m.*³	147,236 cu. ft.	2,483 *m.*³	87,650 cu. ft.
Volume of the inner ship	5,700 *m.*³	201,210 „	2,415 *m.*³	85,250 „	1,491 *m.*³	52,632 „
Difference	2,525 *m.*³	89,133 „	1,756 *m.*³	61,986 „	992 *m.*³	35,018 „
Ratio	0·69		0·58		0·60	

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TABLE VI.—WEIGHTS.

	Design No. 1.		Design No. 2.		Design No. 3.	
	Admiral Paris's Estimate.	Result of Calculations made at La Seyne.	Admiral Paris's Estimate.	Result of Calculations made at La Seyne.	Admiral Paris's Estimate.	Result of Calculations made at La Seyne.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Hull complete	...	2,578·6	...	1,722·4	...	964·5
Backing	...	669·2	...	521·6	...	246·1
Total	4,117·9	3,247·8	3,015·6	2,244·0	1,574·7	1,210·6
Armour-plating and bolts	2,112·1	2,125·9	1,673·2	1,633·8	787·4	856·3
Masts, rigging, and fittings	231·3	374·0	127·9	246·0	57·1	116·1
Crew, baggage, and victuals	275·6	167·3	137·8	98·4	59·0	59·0
Armament	393·7	413·4	157·5	206·6	78·7	118·1
Engine, boilers and water	957·6	1,082·6	717·4	787·4	318·9	393·7
Coal	148·6	787·4	202·7	787·4	275.6	275·6
Total	8,236·8	8,198·4	6,032·1	6,003·6	3,151·4	3,029·4
Displacement	8,236 tons		6,032·1 tons		3,151·4 tons	
Area of immersed portion of midship section ...	1,356·3 sq. ft.		990·3 sq. ft.		714·7 sq. ft.	
Horse-power (nominal)	1,100		800		400	
Ditto in horses of 75 kilogrammètres	6,300		4,600		2,300	
Speed in a smooth sea	14½ knots		14½ knots		12½ knots	
Cost — Armoured hull at 1 franc 38 centimes the kilogramme	8,060,000 francs		5,782,000 francs		3,060,000 francs	
Cost — Engines at 1,360 francs the nominal horse-power	1,500,000 „		1,088,000 „		540,000 „	
Total	9,560,000 francs		6,870,000 francs		3,600,000 francs	

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CONCLUDING PROCEEDINGS.

Mr. CHARLES F. HENWOOD: My Lord, and Gentlemen, I rise in reference to the notice which I gave yesterday, that I would bring before this Meeting two Resolutions; and in doing so I would ask of you the usual indulgence accorded to those who are unaccustomed to speak in public. I find that the first Resolution which I proposed to bring forward had, in a measure, been considered in Council, and that there was a difference of opinion upon it, but no decision I believe had been come to upon the subject. I wish it to be understood that I now bring forward these Resolutions, not in any unfriendly spirit—on the contrary, I should wish and endeavour, as I have always wished and endeavoured, to assist the Council as much as possible in bringing this Institution into general use, and making it of greater public interest. There is no doubt that the duties of the Council are very onerous, and that they have given a very great amount of attention and time towards bringing this Institution to its present state, and I think the thanks of the Members and Associates will be willingly accorded to the Council for what they have already done in that respect. But, my Lord, for my part, I should wish to see this Institution occupy a more prominent position than it has hitherto; and I think the Council might, without taxing themselves to any greater extent, in accordance with the Bye-Laws, avail themselves of the assistance of the Members and Associates, in the way of sub-committees, to further advance the objects and interests of the Institution. The first Resolution which I had originally prepared (and for which it is now my intention to substitute another) was as follows:—"That, in the opinion of this Meeting, considering the "Resolution agreed to on Thursday last to admit Marine Engineers as Members of the Institution, the "Institution should henceforth be styled, 'The Institution of Naval Architects and Marine Engineers.'" But, my Lord, there are objections to that, and I think they will require and deserve consideration. By the Resolution which I have to propose in substitution for that, I think I shall overcome most of those objections. The substituted Resolution is as follows:—"That in the opinion of the Members and "Associates, considering the Resolution agreed to on Thursday last to admit Marine Engineers as "full Members of the Institution, it is desirable to extend this privilege to Officers of the Royal Navy "and Mercantile Marine, Shipowners, Shipbrokers, and others connected and conversant with subjects "embraced by 'Naval Architecture,' and that the professional Naval Architects have the distinctive title "of 'Fellow.'" My Lord, it appears to me that this Resolution will open our doors to a larger number than has hitherto been the case, and I think we shall not find cause to regret taking that step. The various interests which I have enumerated in this Resolution, all contribute to the science of Naval Architecture, and are included in it, it falling within the sphere of a Naval Architect especially to embody all such contributory elements in that one machine—if I may so call it—a ship, whether it be a ship propelled by sails, or a ship propelled by sails and steam. It cannot but be said that a professional Naval Architect would be entitled to a distinctive title; and while Marine Engineers and Officers in the Royal Navy and Mercantile Marine should be admitted as full Members, the distinctive title of the Naval Architect should be that of "Fellow." That is all I have to say upon the first Resolution. With regard

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to the second Resolution which I have to bring forward, I do not anticipate that there can exist much difference of opinion. It is as follows:—"That in the opinion of the Members and Associates, the objects "and interests of this Institution would be greatly advanced by more frequent Meetings, and by the "publication of the *Transactions* in a less expensive form, and in monthly parts." The only question relating to this matter is with regard to the manner of its accomplishment; and that I think we can, with the utmost confidence, leave in the hands of the Council, and I am sure the Members will be willing to render them all the assistance in their power for the attainment of this object. The present limited time does not admit of the Papers being read, and a full discussion had upon them. The Papers, I have observed for a long time past, have not been fully read; nor is sufficient time allowed by the Bye-Laws for the Discussions. No adjournment can take place, however desirable it might be; and the result is, that the *Transactions* record Papers and Discussions as if the entire subjects had been fully discussed and examined, and discussion upon them exhausted. But such, my Lord, is not the case. For instance, only yesterday we had a very important Paper by the Chief Constructor of the Navy, on Long and Short Iron-clads. I need not say how very important that Paper was, as affecting the vital interests of this country. But I think I am right in saying that Mr. Reed did not read more than one half of it, and I am sure the discussion upon it was very much curtailed. I think it was a Paper which, in the usual course of things, instead of occupying us not more than two hours, might have occupied our attention with advantage for two months. With reference to that Paper I would say that I think we were placed very much in the position in which an American audience was once placed by a Lecturer on Astronomy. The Lecturer stated that his audience should disabuse their minds of all they had learned hitherto: the moon was not so big as they had been taught it was—in fact, that it was only 2 feet 6 inches in diameter, and if they did not believe what he said, they were at liberty to go and measure it for themselves. Such was in substance the effect of Mr. Reed's Paper on Long and Short Iron-clads; for there were a great many interesting and important questions raised, and demonstrations put forth, with much ingenuity, but it was impossible to examine or criticise them in so short a time. It appears to me that the proper way of dealing with such a Paper would have been to have read it one day, or one evening, and then to have allowed sufficient time for the consideration of the material points connected with the subject, and to have discussed it at some subsequent date. I am sorry Mr. Reed is not here, because in his presence I should have thought it proper to have further referred to it, but I do not feel myself at liberty to do so in his absence. Again, I very much wished to read a Paper at this Institution this Session, but I was entirely precluded from doing so by the Bye-Laws, and for this reason—that I could not possibly bring the subject within the scope of the time allowed for reading Papers. On the other hand, the subject demanded a greater amount of criticism and examination than is allowed by our Bye-Laws, and on that account I am compelled to take my Paper to another Institution, where I shall read it in the course of a few weeks. There need not be any apprehension about Papers, in the event of our having more frequent Meetings. For instance, take our present programme. I think we might have extended that for three months very advantageously. I would further remark, that it is a very objectionable feature to have day Meetings, when many professional Gentlemen are unable to attend. They cannot give their time during the day; and if the Meetings were always held in the evening, as is the case with the Institution of Civil Engineers, it would be far more convenient. Then one word with regard to the publication of the *Transactions*. I think it is said that the present cost is about £400. It seems to me that that is an ample sum to give us, very satisfactorily, the *Transactions* in monthly parts. I think

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there can be no doubt about that in the mind of any person who has had any experience in publication. I propose that the style of the publication should be maintained, so that at the end of the Session the numbers can be bound up in the usual form if it is desired. I trust in bringing forward these Resolutions, they will be received and accepted in the spirit in which they are made; and, in conclusion, I hope we shall commence our next Meetings at the same time as other Institutions, namely, in the autumn of the present year.

The CHAIRMAN (the Right Hon. the Earl of Lauderdale, K.C.B.): I think the Meeting will agree with me, that there is a great deal in what Mr. Charles Henwood has said. It has struck me frequently that the discussions here are almost useless, because they are never long enough to come to any specific result. I think the Meeting will agree with me, that it would be better to refer it to the Council, who will, no doubt, give it every consideration. Of course there are difficulties in lengthening the time, but if you want to come to any valuable result, you must discuss the thing freely and out; otherwise your time is thrown away.

Rear-Admiral Sir J. C. DALRYMPLE HAY, Bart., M.P., F.R.S.: I think it would be proper to refer it to the Council.

Mr. CHARLES LAMPORT: I have much pleasure in seconding the Resolution which Mr. Henwood last proposed. I think the Meeting will agree with me, that we should not conceal from ourselves the fact that we are not now in that state of prosperity which the utility of the Institution ought to ensure us. Our funds are going down,—there is no doubt about that.

Mr. JOHN SCOTT RUSSELL, F.R.S.: I think they are going up.

Mr. C. F. HENWOOD: You refer to the Government grant.

Mr. LAMPORT: That is something extraneous, and I think eleemosynary aid, after all, ought to be looked upon with something like suspicion. I should be sorry if an Institution of this kind were not able to maintain its own position. One thing that Mr. Henwood has referred to is the great expense of the publication of the *Transactions*. I quite agree with a popular author, who said that the size of the book should never be beyond that which you can hold in your hand. We do not want such detailed reports. The slight sketches which are given in the publication called the *Civil Engineer*, in the small pages of an ordinary pamphlet, are everything that is necessary even with reference to the most complicated subject. The diagrams are mere sketches, but those extended lines of our Report, wrapped up as they are in that expensive book, waste away the sinews of war of this Institution; therefore I cordially endorse what Mr. Henwood proposes with reference to a small periodical publication of our *Transactions*. With regard to more frequent Meetings, I do not think I need say much. I know that we are an exception to all other scientific bodies. There is a reason for that. London being the head quarters of civil engineering science and art, meetings on such subjects are easily brought about; but we are scattered all along the coast, and when Meetings take place, they should be arranged so that Members can come to them. It strikes me very much in this way. It is no good to give a person more than he can eat and digest. But we are in a state of chronic starvation, with periodical repletion. I put it to you, whether the usefulness of this Institution would not be enhanced, and more spirit imported into the Discussions, if we had a better opportunity of considering the subjects brought before us. My opinion is very strong, indeed, that the real value of these Meetings consists not so much in

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the Papers read, as in the collision of intellect with intellect, striking an intellectual fire as it were from flint and steel. We want a subject lucidly brought before us, and we do not want mathematical formulæ which nobody can follow. I defy my friend Mr. Rawson, or even Mr. Merrifield himself, to follow many of the elaborate formulæ which are given in many of the Papers. They are passed over, the very pith and marrow of the Paper is not read, and we are then called upon to discuss the subject. If the Papers were published in a periodical, and notice were given of more Meetings to take place, and people came prepared to discuss the subjects to be dealt with, I think more good would be done. At all events, we should not come here, feeling that we are committing a sort of social transgression if we go a minute beyond our ten minutes for speaking, or a minute beyond our forty minutes for the whole discussion. Although conversation upon such subjects is excellent, such pressure puts to flight many of the ideas which might otherwise form germs to be developed by more elaborate consideration and discussion. I therefore have great pleasure in seconding the Resolution which has been proposed by Mr. Henwood in that respect; and it may save time if I go on to move another Resolution, which I was invited to propose last night. Those Gentlemen who were present at our Opening Meeting may call to mind that the President suggested to me, that the propriety of a recommendation to the Council to use its influence by representation to the Admiralty to obtain reliable *data* bearing upon Fluid Resistance, would be better discussed when the Paper read by Mr. Thornycroft was brought before the Meeting. My Lord, I confess I could not exactly see how it had any application, but I acquiesced, as I was bound to do, in the suggestion of our President. We did discuss it last night, and in consequence of that discussion, and a recommendation from Mr. Scott Russell, I have now the pleasure of submitting to you a Resolution, to act as a spur or recommendation to the Council to do something towards the collective and associative action of the Institution. I beg to move the following Resolution:—"That this Meeting, "impressed by the advantage which would arise from the collection of reliable information on material "matters in connection with Naval Architecture, urges upon the Council that it should use its influence, "first, to induce the Admiralty to institute experiments to determine proper *data* for the resistance of "iron masts of various relative proportions to the compound strains to which they are exposed at "sea; and, second, to institute experiments to shew the actual water resistance of representative ships of "various classes, by testing the same by the use of the dynamometer."

Mr. ROBERT RAWSON: I have very great pleasure in seconding the Resolution which has been proposed by Mr. Lamport, concurring as I do in that which he has been endeavouring to lay before the Meeting. I believe in the interference of ideas, as well as in the interference of light, that sometimes two ideas cross each other in the mind, and make a dark place, and that it is quite possible, in feeding the mind, we may take more than we can digest, which is a great evil. I think that too many things are brought before us at the same time. I am sure many things were put upon the black-board last evening that would take me two or three months to fully comprehend and to know what they were all about, yet all these things have to be done in a few minutes; and, speaking with respect to myself, the observations that I ought to make when I see the formulæ on the board, occur to me two or three weeks hence. They come upon one's mind when the opportunity for discussion has passed away. These subjects should be brought before the Members in some shape or form before they are put on the black-board, either by a circular, or something of that kind, so that individuals attending here to discuss the subjects might be prepared to do so, and not have their notions generating respecting the particular subjects

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some time afterwards, when they are of no use, and when the people that ought to listen to them are all gone away. I think there is a great deal in what has been said as to having too much food for the mind. We may eat too much, and drink too much, but it will not go to supply strength to the body, so with respect to the mind—we may have too much upon it; we may have notions and ideas crossing and recrossing, and interfering with each other, causing dark, not bright places, and lose ourselves in a maze and mass of confusion. I think it would be a very good thing if we could have all these subjects brought before us, as Members, a little before we have to come here to discuss them. No one can fail to see the vast importance of correct experimental *data* of the kind referred to in Mr. Lamport's Resolution, therefore I have great pleasure in seconding it.

Sir J. C. D. HAY: I think that the suggestion which fell from your Lordship just now is probably the one which it would be most agreeable to the Meeting to follow. I think it impossible that we can, at this Meeting, discuss whether it is the pleasure of the Meeting to adopt these Resolutions. I am quite sure that although there is so much in them which may appear to be good to the majority of Members and Associates present, yet there is so much in them that may require discussion to put them in a practicable shape, that I shall have great pleasure in moving that these Resolutions be referred to the consideration of the Council.

Mr. LAMPORT: That is the object of my Resolution.

Mr. C. F. HENWOOD: I proposed them to be brought before the present Meeting.

Mr. SCOTT RUSSELL: I think every Member of the Council will feel extremely grateful for these suggestions. I am quite sure that every Member of the Council will give his very best consideration and care to see how far such reasonable wishes as have been expressed can be successfully carried out; therefore, instead of offering any opposition to them, I would do, as I certainly have done with regard to one of these propositions—namely, give my cordial support, believing that every Member of the Council will look into the matter just as you yourselves are disposed to do; and if we can advance the usefulness of the Institution in any way, I can assure you, from my experience of a very numerous Council, that they care for nothing in the world except what will best further the interests of this Institution, and carry out the wishes of the Members.

Mr. C. F. T. YOUNG: It was proposed by Mr. Henwood that the *Transactions* should be brought out oftener—monthly if possible. It has struck me that there is now a favourable opportunity of doing so, by founding a Journal of the Institution as a recognised means of disseminating knowledge, otherwise than at the Meetings. I confess I do not see the difficulty of it. There is the Society of Arts, which numbers 4,000 members, who publish a Journal, and maintain very good weekly Meetings. I do not think it would be found at all troublesome or out of the way. I think it is a suggestion well worthy of consideration.

The CHAIRMAN: Perhaps the Council will take these propositions into their consideration.

Mr. SCOTT RUSSELL: As I believe we may now consider the business of this Meeting at an end, I will take the liberty of moving a Resolution in which I know we shall be unanimous. Ever since this

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Institution was founded, we have seen that a Gentleman of high political position, charged with enormous responsibilities, and having his time taken up by matters of national importance, has been good enough to leave those duties, and occupy himself as a Member of this Institution in presiding at all our Meetings, whenever it was practicable for him to wrench himself away from public duty. You will agree with me that Sir John Pakington is in every respect an admirable President of this Institution; and when I tell you that he takes the trouble of attending the Council Meetings and the Committee Meetings, and is probably the hardest working man in the Institution, I am sure you will all concur with me in feeling that our very best thanks are due to him, and that we owe very much of the success of these Meetings to the zealous occupation of his time with our proceedings (applause). Next to him, I will ask you to return thanks to the Chairman, who has been good enough to take the place of our President. I will not pay him the same compliment; but I will pay him another, and that is, that we should like to see him a great deal oftener where he is (cheers). I have but a few words more to say. I believe you would find fault with me, if I did not tack on to the present motion that our Honorary Secretary, who also fulfils duties of a very onerous kind, and who devotes himself, without remuneration, to the labours of Secretary of this Institution deserves our warmest thanks, and our expression of regret that it is quite out of our power to give so valuable a man the remuneration which his services would entitle him to (cheers). In doing so, let me also console the Members with regard to our revenue. Our expenses are diminishing, and our revenue is looking up, as they say, in the market; therefore, I pray you, do not at all indulge yourselves in any despair as regards our prospects. I will just correct one or two little misunderstandings which I daresay may be in the mind of one or two of the Members, because they were in my own mind. In my own mind, some time ago, I said, "Dear me! How is it that the numbers of this Institution are so much smaller than the numbers of so many other societies?" I looked into the matter, and I found it to stand thus: that whereas people were saying we had not got Members of the Institution enough, I found that we had every member of the profession that was worth having. You must remember that there is not an infinite number of naval architects, and there is not an infinite number of shipbuilders in Great Britain; and fortunate it is that there is not an infinite number, for there is competition enough with the number we have, and I would rather that naval architects and shipbuilders in this country preserved the moderate number which they now possess. With regard to the other points mentioned, I would add that we are very anxious to open this Institution, to invite Members to this Institution, and to make it pleasant to them; we are very anxious to have the co-operation of as large a number of men, whose avocations are analogous to and work into our own, as possible; we are most earnest to have engineers who take an interest in and are associated with naval architecture; we are most anxious to have sailors, who must inevitably take an interest in naval architecture—we are very anxious to have them here, and very anxious to make it pleasant to them in every respect. But there is just one little thing which I think you ought to remember. There are a great number of other Institutions which are Institutions of engineers exclusively, and we are admitted there as Associates, and are very happy to go in as Associates. There are Institutions also of sailors—the United Service, for example—and we are very glad to go there, and very glad to be admitted as Associates. I think you must stop somewhere, and I think it is well that we should continue to be what we began to be—an Institution of Naval Architects; and then let us understand that every sailor who has shown an interest in naval architecture and studied naval architecture, and acquainted himself with it in such a manner as to desire to be one of us, will be most welcome here; and, in like manner, any engineer who has taken the pains

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to qualify himself to co-operate with us in naval architecture, will also be most welcome here; but that we should alter our name for that, into an Institution of Naval Architects, Engineers, and Sailors, is quite another question.

Mr. C. F. HENWOOD: It is not proposed that we should do so.

Mr. SCOTT RUSSELL: It is not proposed; but that we should do that, is the last thing I should think of proposing. These are all the observations I have to make. In conclusion, I think you will agree with me that the officers I have mentioned deserve our best thanks, and that in giving them your thanks, you will also give thanks to Lord Lauderdale for presiding over us on the present occasion.

Vice-Admiral Sir EDWARD BELCHER, K.C.B.: I have much pleasure in seconding that which Mr. Scott Russell has proposed. [The motion was carried with acclamation.]

The CHAIRMAN: Gentlemen, I can only say that I am proud of receiving your thanks. It always gives me great pleasure to be here, for I gain useful knowledge with reference to a subject in which I am very much interested.

Sir E. BELCHER: I have to make a short motion before we separate. We are in the enjoyment of this Hall by permission of the Society of Arts, and I think our thanks are due to them for their kindness. I may add that one difficulty in the way of extending our time hitherto has been because they could not spare this Hall beyond a certain period; but it is to be hoped that we shall get over that difficulty, which will enable us to have longer Meetings in future.

Mr. SCOTT RUSSELL: I beg to second that. [Carried with applause.]

The business of the Tenth Session then terminated.

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NOMINAL INDEX.

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NOMINAL INDEX.

BEING AN ALPHABETICAL LIST OF THE NAMES OF THE AUTHORS OF PAPERS READ BEFORE THE INSTITUTION, AND OF THE SPEAKERS WHO TOOK PART IN THE DISCUSSIONS WHICH FOLLOWED THE READING OF THE PAPERS.

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Belcher, Sir Edward ...	Suggestions for a floating dock	29
	The question of a dock at Bermuda	29
	Proposal to refer Mr. Henwood's Resolutions to the Council ...	117
	Reasons for deferring the consideration of the Resolutions ...	118
	Example of the sensitiveness of the magnetic needle	134
	Mr. Scoresby's experiments	134
	Revère's plan for applying a magnetic test to iron	134
	All iron liable to shew defects under the magnetic test ...	134, 135
	Imperfection of the welds in the Armstrong gun	135
	Preliminary arrangements for the Session of 1870 ...	151
	Necessary to have naval men to communicate with the Admiralty	153
	On various kinds of life-buoys	163
	Method of pointing out a man in the water to the boats sent to him	164
	Moving vote of thanks to the Society of Arts for the use of their Hall	225
Bell, Benjamin ...	*On zinc sheathing for ships*	174
	Difference of behaviour in copper and zinc if a portion of the sheathing be removed through accident	194
	Moderate rapidity of decay in zinc an advantage in using it as sheathing	194
	Zinc of commerce, impure	194
	Objections to the plans of sheathing adopted in the *Inconstant* and *Volage*	195
Bourchier, Commander W. S.	*On the preservation of life at sea by life-buoys and rafts*	155
	Objections to the Admiralty life-buoy	165
Bower, A.	Advantages of Mr. Mac Farlane Gray's steam steering apparatus	115
Bramwell, F. J.	Perforation of armour plates	15
	St. Thomas' Dock in litigation	27
	Floating dock constructed by one Watson in 1774 ...	28
	Stability of floating docks	28
	Objections to iron graving docks	29
	Comminuted coal, and its advantages	40

Digitized by Google

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Bramwell, F. J.	Means for regulating the admission of air when burning liquid fuel	40
Byrne, Oliver ...	Modern iron-clads deficient in coal carrying power	38
Council of Institution ...	*Eighth general report*	xvii.
Cowper, E. A. ...	On the relative advantages of steam and hydraulic steering apparatus	114
	"Marshall's" iron	132
	Objections to a secret test for iron	132
De Horsey, Captain A. F. R.	The question of a dock at Bermuda	27
	Railway ferries on the Canadian lakes	58
	Long ships much impeded by friction	86
Drew, Rev. Mr. ...	On various kinds of life-buoys	163
Fairbairn, William ...	*On the law of resistance of armour plates, composed of one or more thicknesses*	1
Fenning, W. M. ...	Objections to a ferry between Dover and Calais	56
Grantham, John	The dock question generally	27
	Advantages of the different descriptions of floating docks ...	28
	No great difference between the requirements of merchant vessels and of ships of war	87
	On copper sheathing for iron ships, considered at the present stage of our experience	166
	On the details of his plan for sheathing iron ships with copper	191
	Objections to Mr. Bell's and Mr. Daft's plans of sheathing iron ships with zinc	192
	Objections to galvanizing iron	192
	Saturation of the wood sheathing without effect on galvanic action	192
Gray, John Mac Farlane ...	On a new formula for steam ship performance	83
	On the steam steering apparatus fitted in "Great Eastern" and other vessels	101
	On Captain Inglefield's steering apparatus	112
	Method adopted for preventing the condensation of the steam in the cylinders of his steam steering apparatus	113
	Trial of the steam steering apparatus on board the *Northumberland*	113
Haswell, Charles	*On the location of independent steam, fire, and bilge pumps in steamers*	197
Hay, Sir J. C. D. ...	Experiments on armour plates	15
	Effect of African waters upon zinc	186
	Importance of a good sheathing for iron men-of-war ...	186
	Relative advantages of zinc and copper as sheathing for ships ...	186
	Motion to refer Mr. Henwood's and Mr. Lamport's Resolutions to the Council	223
Henwood, Charles F. ...	Notice of Resolutions to be moved, concerning the name of the Institution and its *Transactions*	117
	Objection to referring the Resolutions to the Council ...	117

Digitized by Google

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Henwood, Charles F. ...	Moving Resolutions with reference to the constitution of the Institution, and to the *Transactions*	219
Holland, J. S. ...	*On horse-power*	201
Inglefield, Rear-Admiral E. A.	Advantages of a short ship over a long one	89
	On the hydraulic steering gear as being fitted to H.M.S. "Achilles"...	92
	Advantages of a water engine in hydraulic steering gear ...	100
	Further explanations with regard to his hydraulic steering gear	116
	Water engines economical in repairs	116
Key, A. C., Rear-Admiral	On hydraulic steering gear	98
King, William Poole ...	Action of barnacles	184
	Behaviour of zinc in sea water	184
	On sheathing composite ships with copper	185
Lamport, Charles ...	Reliable data on certain subjects required by shipbuilders ...	xxiv.
	Graving docks *v.* floating docks	26
	Explosive character of liquid fuel	41
	Comparison of *Bellerophon* and *Minotaur*, as to economy ...	81
	Liability of iron to become magnetic through percussion a drawback to the infallibility of any magnetic test	131
	Moving a Resolution with reference to the resistance of ships ...	221
	Necessity of experiments on the resistance of vessels ...	150
	Notice of Resolution on the subject of resistance of vessels ...	153
	Wood a galvanic conductor when saturated with salt water ..	182
	Objections to galvanised iron bolts	183
	Remedy for the decay of iron bolts in composite ships ...	183
	Notice of a Paper to be read at the session of 1870	195
	Seconding Mr. Henwood's Resolutions	221
Lauderdale, Earl of ..	Advantages of a fine long bow over a bluff one	82
	Instances of rapid decay of copper sheathing	195
	Proposal to refer Mr. Henwood's Resolutions to the Council ...	221
Lungley, Charles ...	On his plan for sheathing iron ships with zinc	193
Merrifield, Charles W. ...	Reasons for deferring the consideration of Mr. Henwood's Resolutions	118
	On Mr. Thornycroft's formula for the resistance of vessels moving through water	148
	Committee of British Association appointed to enquire into the behaviour of ships	150
Olrick, Lewis ...	Description of the *Aydon* system of burning liquid fuel ...	41
	Insurance offices reconciled to the use of liquid fuel ...	41
	Harmless character of explosions if oil of a high specific gravity be used	42
	Discussion of Dr. Paul's pamphlets on liquid fuel ...	42, 43
	Example of evaporative effect of liquid fuel	43
	Price of liquid fuel	43
	Responsibility of a manufacturer for using bad iron ...	133
Pakington, Sir J. S. ...	Opening address at tenth annual meeting	xx.
	On the discussion of abstruse technical Papers	16

Digitized by Google

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Pakington, Sir J. S. ...	Importance of Bermuda as a naval station	31
	The question of floating docks in its infancy	31
Pâris, Admiral E. ...	*On sea-going turret ships*	206
Rankine, W. J. Macquorn ...	*On the calculation of the stress in propeller shafts*	139
Rawson, Robert ...	Seconding Mr. Lamport's resolution	222
	The direction and position of the resistance to a ship must be considered as well as its intensity	85
	Length of a vessel influences the after resistance	85
Reed, E. J.	On the discussion of abstruse technical papers	14
	The resistance of armour plates	14
	Capability of ships of war to carry coal	39
	Consumption of coal on board the *Hercules*, *Serapis*, and *Crocodile*	39
	Steaming capabilities of iron-clads	39
	On long and short iron-clads	59
	On the *Warrior's* coal-carrying powers	88
	Advantages of the balanced rudder over twin screws, so far as handiness is concerned	89
	Bellerophon intended to meet the same class of enemy as the *Warrior*	89
	His own ships have longer middle bodies than the *Warrior* ...	89
	The French given to building short iron-clads	89
	Advantages of a short ship over a long one in pitching ...	90
	Advantages of twin screws in case of an accident with one engine	90
	Distinction between the qualities of a merchant vessel and a ship of war	90
Rennie, G. B. ...	*On the iron floating dock of Carthagena, its proportions and relative stability*	17
Reynolds, W. F.	*On an instrument for determining the deviation of ships' compasses*	
Rochussen, T. A. ...	On the manufacture of iron and steel	131
Russell, John Scott ...	*See* Scott Russell, John	
Saxby, Stephen M. ...	*On the qualities of boiler plate*	119
	On the nature of the magnetic test	130
	The test not yet perfect	136
	Further experiments with it necessary	137
	Steel more easily tested than iron	137
	Testing the paddle-shaft of the *Virago*	138
	Magnetic testing extremely simple and cheap	138
Scott, Captain R. A. E. ...	Cruise of the *Hercules* to Lisbon	86
	Good qualities of the *Bellerophon*	86
	On twin screws	87
Scott Russell, John ...	The resistance of armour plates	14
	Relative advantages of the platform and ship-shape forms of floating docks	30
	Suggestion for a floating dock to accompany steam fleets of war	30
	On the different states assumed by fuel	45
	On railway communication across the sea	47, 55 *et seqq.*

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Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Scott Russell, John ...	On the design of the *Warrior*	77 to 79
	Comparison of *Bellerophon* and *Warrior*	79
	On speed and handiness	80
	On hydraulic steering gear	98, 99
	Proposal to refer Mr. Henwood's Resolutions to the Council ..	117
	Moving votes of thanks to the Officers of the Institution ...	223
	On the labours of the Steam-Ship Performance Committee ...	151
	Difficulty of inducing the Admiralty to institute experiments with ships	152
	Experiments necessary for the determination of the resistance of ships	152
	Fallacy of using indicated horse-power as a criterion of the resistance of ships	153
	Every ship ought to be built for some particular velocity ...	154
	On Mr. Grantham's plan of sheathing iron ships with copper ...	189
	Objections to zinc sheathing	190
	On Mr. Henwood's and Mr. Lamport's Resolutions	223
Selwyn, Captain Jasper H. ...	*On the progress of liquid fuel*	32, 43 *et seqq.*
	Advantages of a flaring bow	82
	On the wedge bow	83
	Advantages of Mr. Saxby's magnetic test	136
	Objections to Commodore Bourchier's life-buoy	164
	Wood not a perfect insulator	191
Siemens, Charles W. ...	Reason why liquid fuel gives a better result than coal	38
	On railway ferries	55
Thornycroft, John S. ...	*On the resistance opposed by water to the motion of vessels of various forms, and the way in which this varies with the velocity* ...	144
	Constants employed in the formula	149
Wigram, Charles H. ...	*On a project for a floating dock*	23
Young, C. F. T.	On the sheathing of ships	187
	Proposal to publish a Journal of the Institution	223

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Fig. 1.

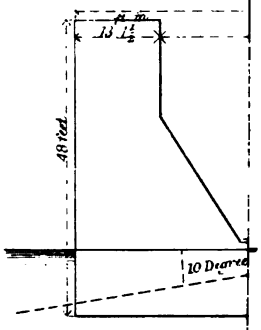
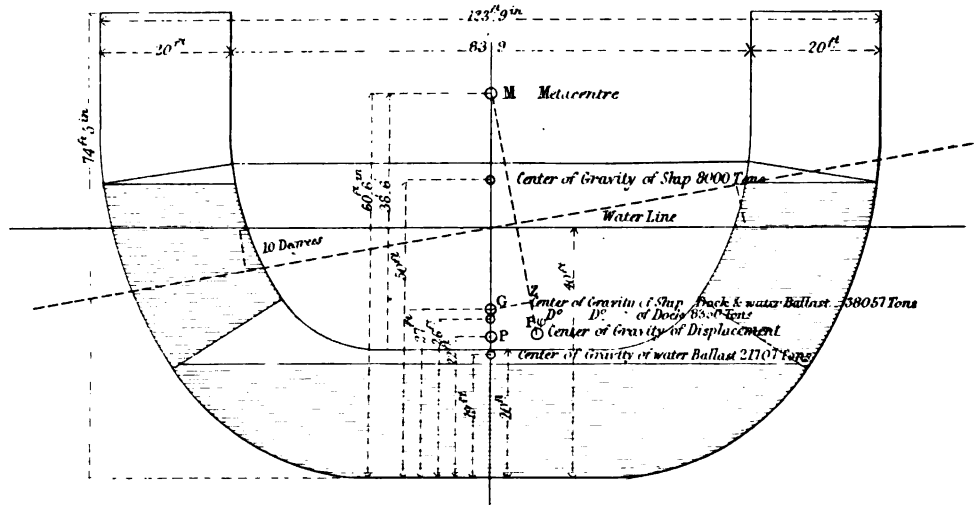
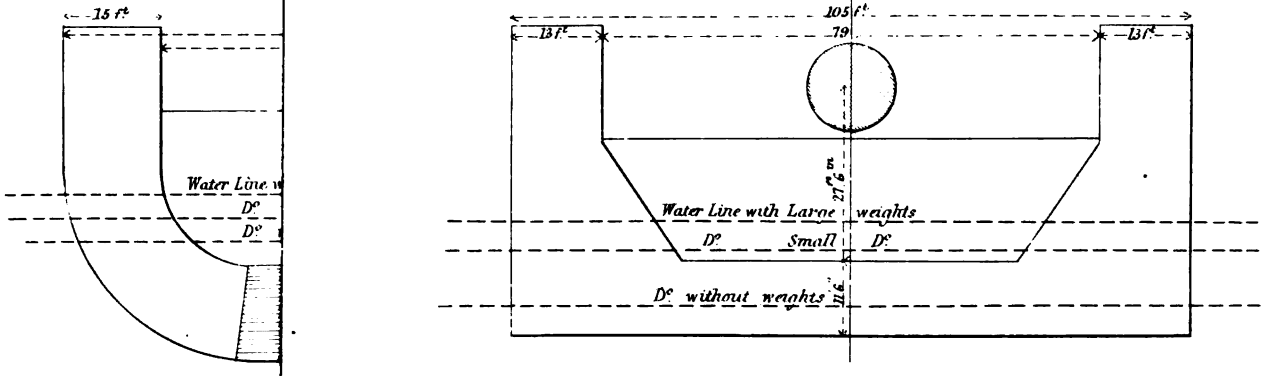


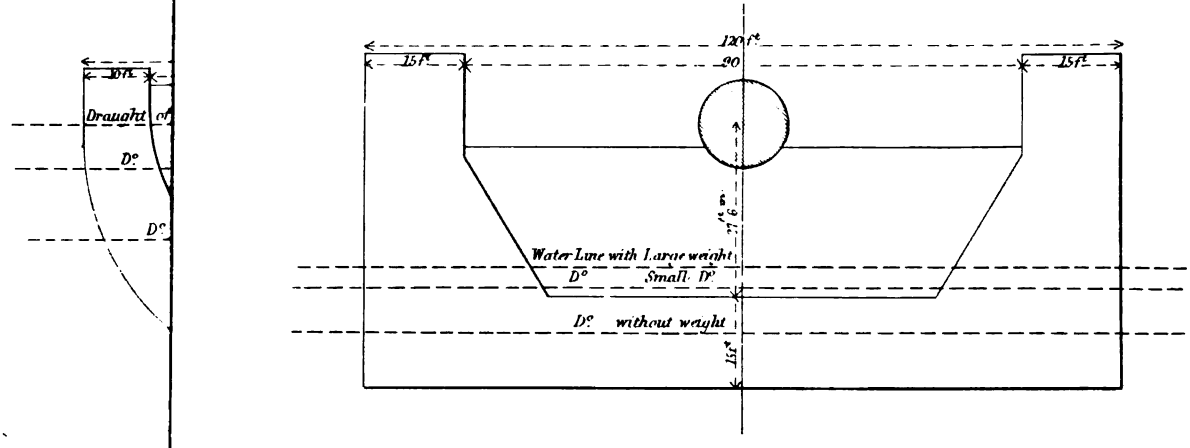
Fig. 3. Section of Bermuda Dock.



Section of Model (E)



Section of Model (A).



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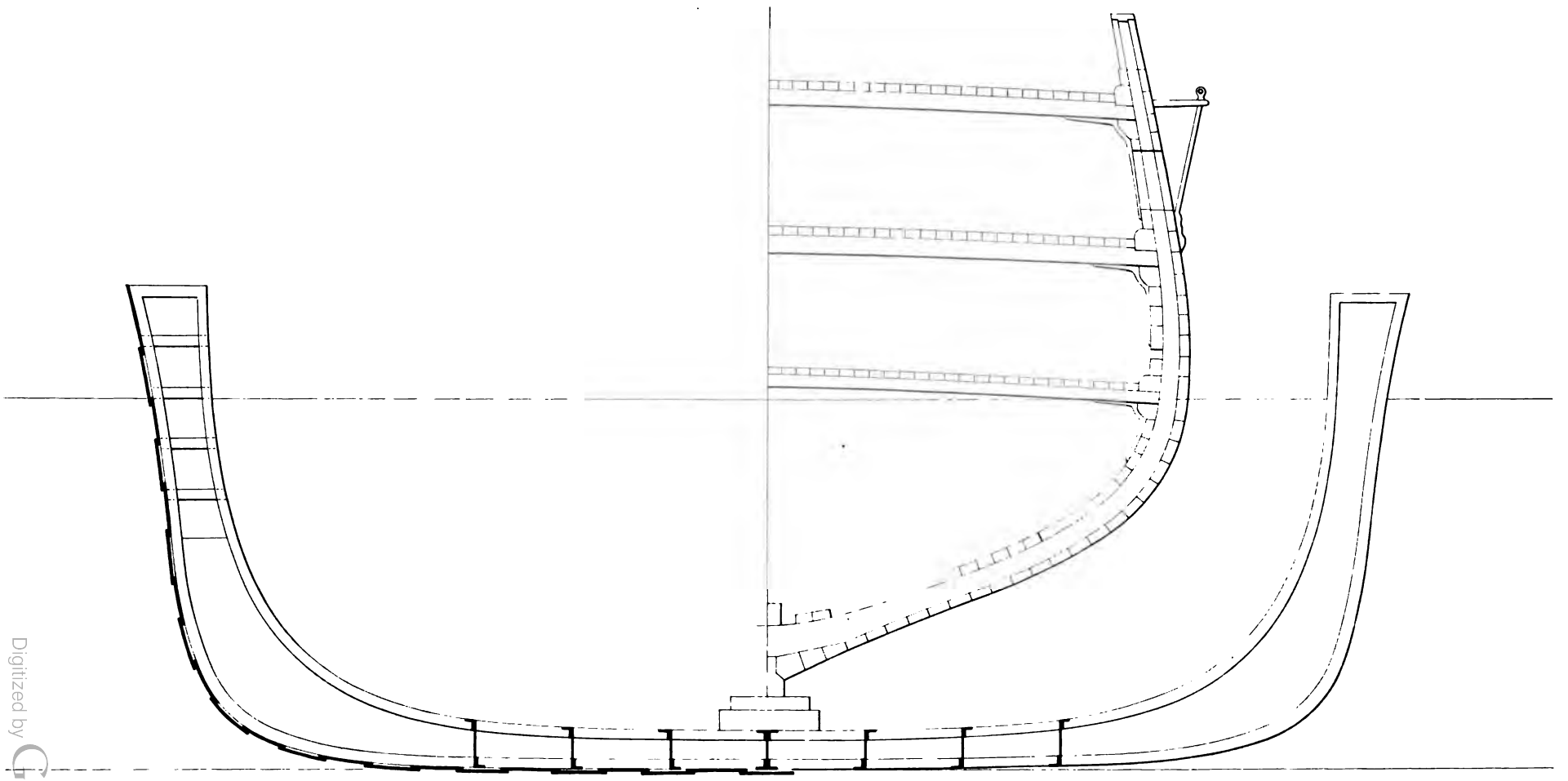
To illustrate Mr. Charles H. Wigram's Paper on a project for a Floating Dock.



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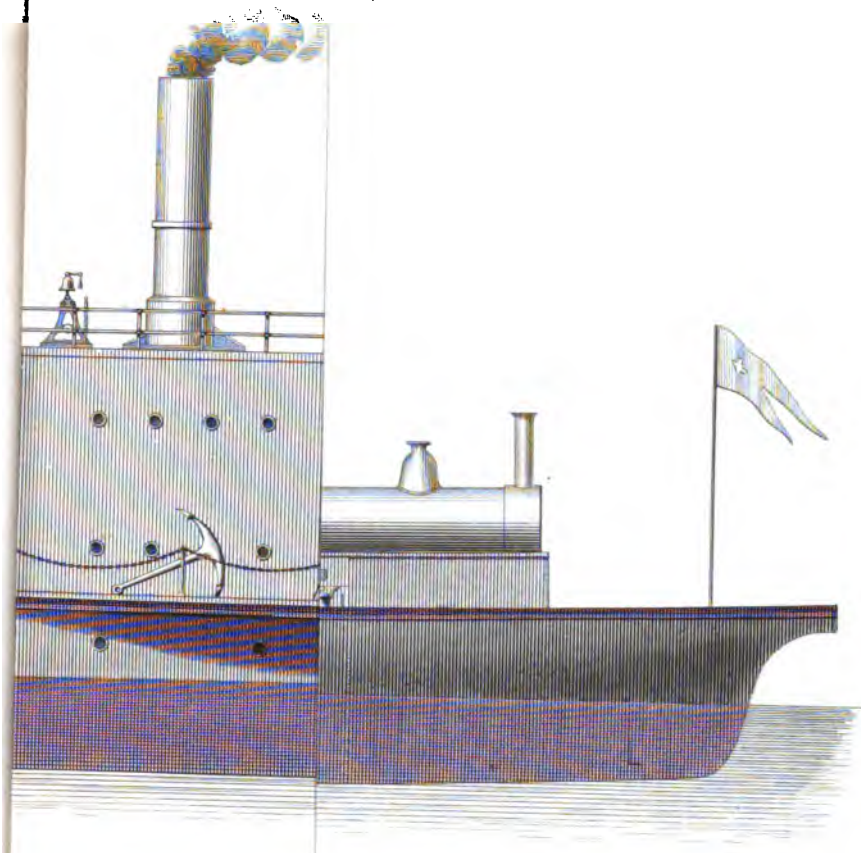

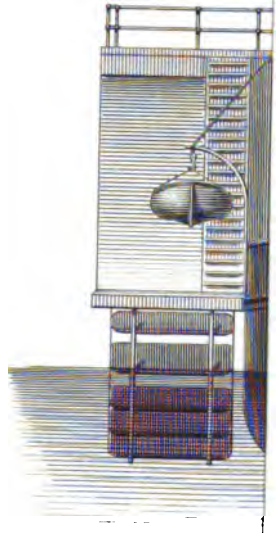

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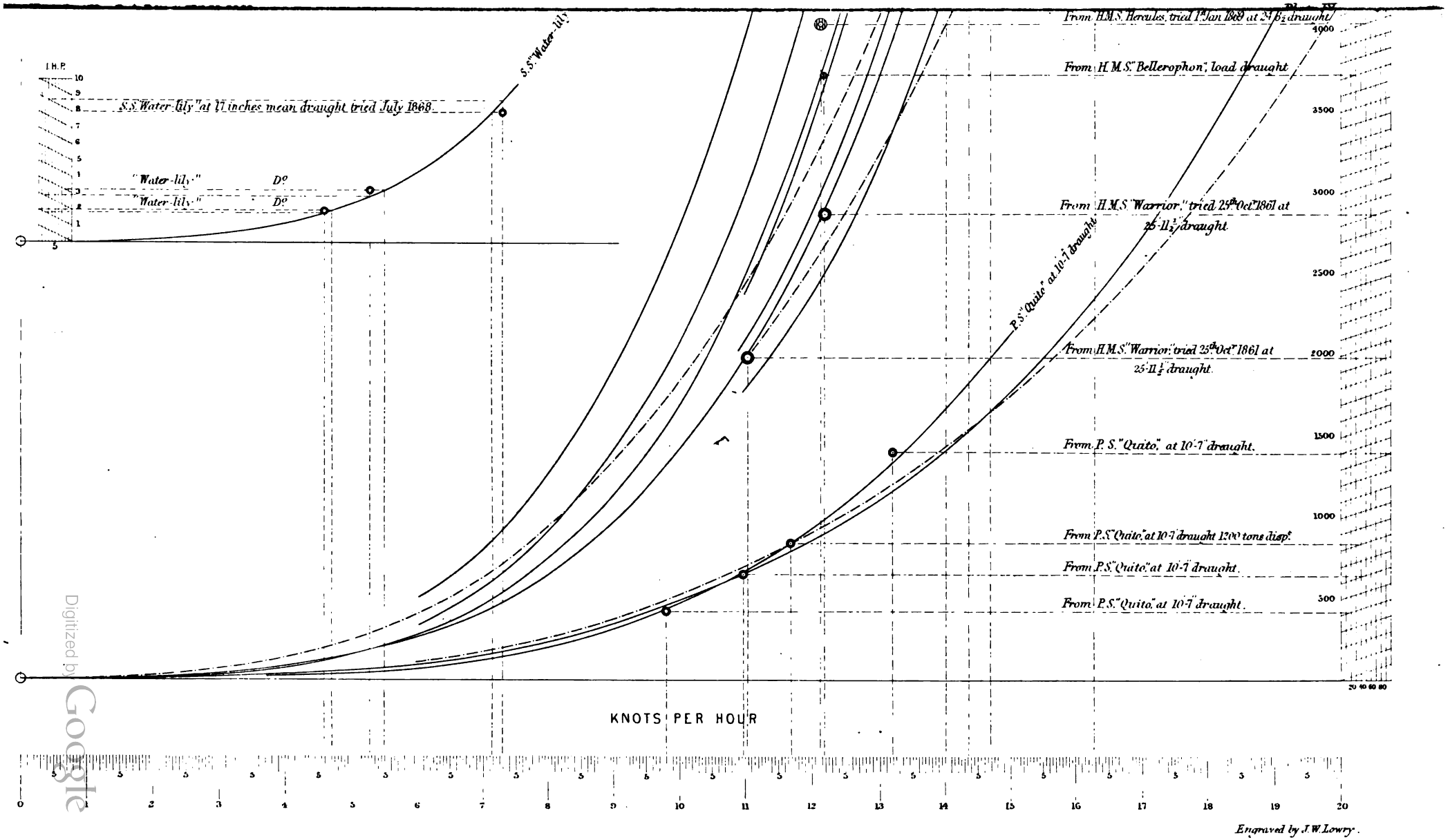

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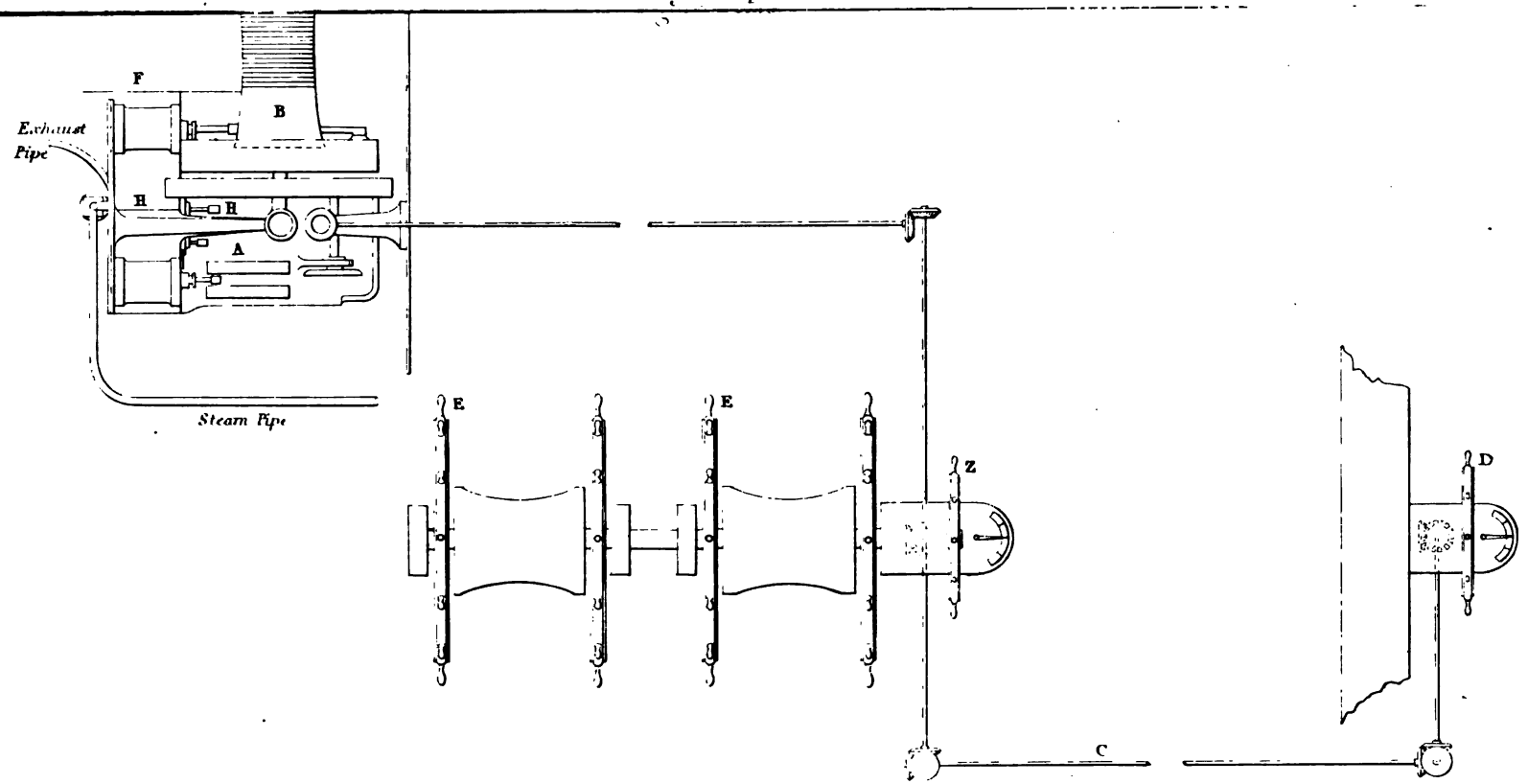

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